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LOWER PERMIAN CORRELATIONS IN CLEVELAND, McCLAIN, AND GARVIN COUNTIES, OKLAHOMA[1]

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ABSTRACT

New correlations of the subdivisions of the Enid group of McClain and Cleveland counties, with the stratigraphic units described in Garvin County, are proposed. The base of the Permian is placed at the base of the Asher formation of Morgan, and at the base of Unit 1 of Dott, rather than at the Hart limestone, as proposed by Morgan. The Stillwater formation is thought to be equivalent to Unit 1 in Garvin County, and the Wellington formation to Unit 2. The Garber formation is thought to include Units 3-6 inclusive, and the Hennessey formation to include Units 7 and 8. These correlations are based on lithologic similarity, the sequence of beds, similar thicknesses, and on the presence and position of such markers as zones of barite rosettes and pseudo-conglomerates.

ACKNOWLEDGMENTS

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INTRODUCTION

The extension of drilling into the Permian area of south-central Oklahoma during the past few years has led to a more intensive study of the Red-bed formations, and many of the perplexing problems of stratigraphy are rapidly progressing toward solution.

[1]Manuscript received, May 6, 1931.

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In 1926, Aurin, Officer, and Gould[1] re-defined the old term Enid, raising it from the rank of formation to that of group. They subdivided it into six members, and correlated them with the Kansas formations as shown in Table I.

TABLE I

CORRELATION OF ENID GROUP AFTER AURIN, OFFICER, AND GOULD

Kansas	*Oklahoma*
Flower Pot shale Cedar Hills sandstone	Chickasha formation
Upper Harper sandstone Middle Harper sandstone	Duncan sandstone
Lower Harper sandstone	Hennessey shale
	Garber sandstone
Wellington shale	Wellington shale
Upper-Marion formation Pearl shale member	
Lower Marion formation Chase formation Council Grove formation	Stillwater formation

It is understood that more recent work has necessitated several changes in this correlation, and that revisions will be made. These, when published, will be the results of several years of study by field geologists working in western Oklahoma.

The map of Aurin, Officer, and Gould showed the areal distribution of these formations from the Arbuckle Mountains northward. The correlations in the southern area were less definite than in the northern, and the contact lines as mapped were tentative. The Stillwater of the northern area was thought to include the Asher, Konawa, and Stratford formations of Morgan.[2]

In 1927, Clark and Cooper[3] described the formations in Kay, Grant, Garfield, and Noble counties. They followed Aurin, Officer, and Gould,

[1]F. L. Aurin, H. G. Officer, and Charles N. Gould, "The Subdivision of the Enid Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 8 (August, 1926), p. 791.

[2]George D. Morgan, "The Geology of the Stonewall Quadrangle," *Bur. of Geol. Bull. 2* (1924).

[3]G. C. Clark and C. L. Cooper, "Oil and Gas Geology of Kay, Grant, Garfield, and Noble Counties," *Oklahoma Geol. Survey Bull. 40-H* (1927).

except that they put the base of the Stillwater at the base of the Neva limestone, instead of at the base of the Cottonwood.

At nearly the same time, the writer[1] described the Red-beds of Garvin County, giving an eight-fold subdivision of the beds from the top of the Pontotoc to the base of the Duncan sandstone (Fig. 1). An attempt was made to correlate these eight units with the subdivisions of Aurin, Officer, and Gould, but this correlation, unfortunately, was in error, and should be disregarded.

Later, Anderson[2] described the geology of Cleveland and McClain counties, following the classification and mapping of Aurin, Officer, and Gould, with more detailed tracing of formation boundaries. His classification is considered by the writer as generally correct, except for the position of the base of the Stillwater formation. In that article, Anderson proposed a correlation of the beds in Garvin County with his subdivisions in McClain and Cleveland counties. It is this correlation which the writer wishes to discuss.

In Garvin County, 1,135 feet of Red-beds were measured with rod and plane table, from the top of the Pontotoc formation to the base of the Duncan sandstone. In McClain County, Anderson gives 1,340 feet (1,090 feet without the Konawa) for his pre-Duncan Enid, and in Cleveland County, without the Stillwater, approximately 1,400 feet. In the northern area, the total thickness of these rocks is 2,470 feet.

BASE OF PERMIAN

Aurin, Officer, and Gould, and Anderson have accepted Morgan's[3] determination of the base of the Permian as the Hart limestone, which marks the base of the Stratford formation of the Pontotoc terrane, and have included Morgan's Konawa and Stratford formations in the Stillwater. This the writer is unwilling to do.

Morgan placed the top of the Pennsylvanian within his Pontotoc terrane, which he subdivided as follows.

SUBDIVISIONS OF PONTOTOC TERRANE, AFTER MORGAN

Pontotoc terrane	Konawa formation
	Stratford formation
	Vanoss formation

[1]Robert H. Dott, "Geology of Garvin County," *Oklahoma Geol. Survey Bull. 40 K* (1927).

[2]G. E. Anderson, "Geology of Cleveland and McClain Counties," *Oklahoma Geol. Survey Bull. 40-N* (1927).

[3]George D. Morgan, *op. cit.*

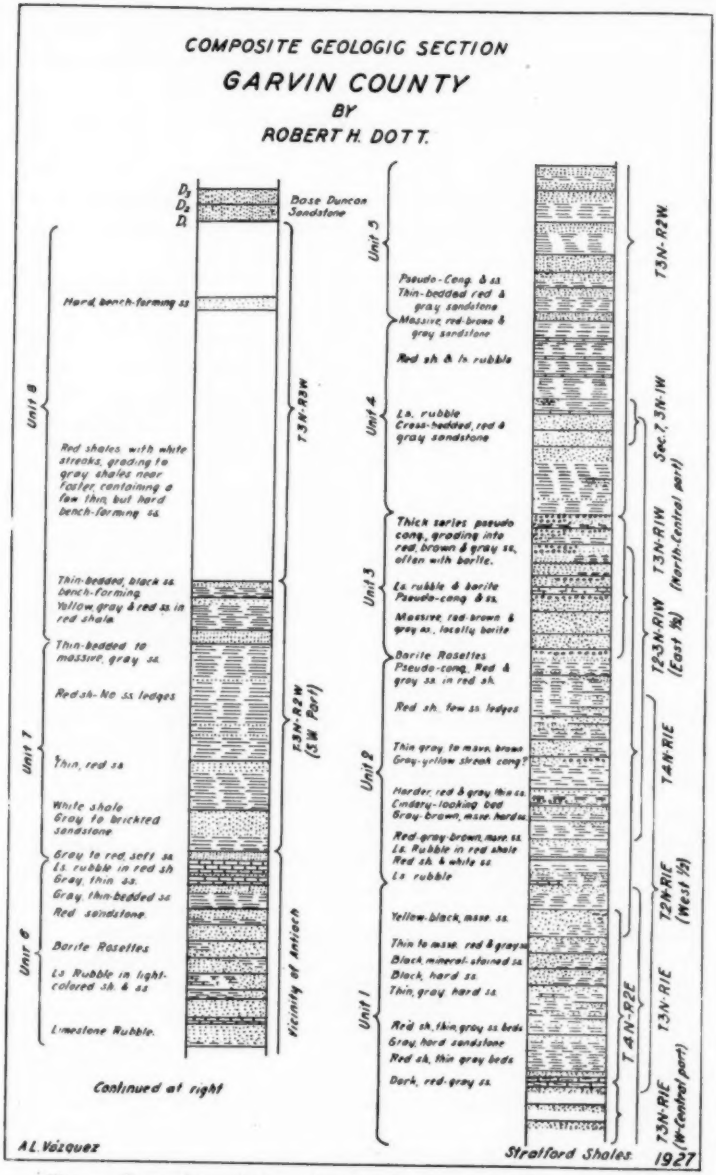


FIG. 1.—Composite geologic section, Garvin County, by Robert H. Dott. From "Geology of Garvin County," *Oklahoma Geol. Survey Bull. 40-K* (1927), p. 13, Fig. 2. Also "Oil and Gas in Oklahoma," *Oklahoma Geol. Survey Bull. 40*, Vol. II (1930), p. 125, Fig. 19.

He was in considerable doubt as to the relationship of the Konawa and Stratford formations, but concluded that the Konawa overlapped the Stratford. The writer believes the two to be equivalent, as previously indicated.[1] Morgan found a species of the plant genus *Walchia* near the top of the Vanoss formation, and it is principally on this basis that he refers the Stratford and Konawa to the Permian. He states that David White said: "....although a *Walchia*, it (Morgan's specimen) is not clearly the species *Walchia pinniformis*," though comparable with that species.

Walchia pinniformis has been reported by Sellards[2] and White[3] from the Wreford and Wellington in Kansas.

Morgan further quoted David White, as follows.

> There are a number of cases in which it is clear that *Walchia* is present in the uppermost horizons of the Pennsylvanian. Yet it is in general so characteristic of the Permian that each such case deserves special inquiry.

In Kansas, the upper Pennsylvanian is known as the Wabaunsee formation, and the overlying lower Permian as Council Grove, Chase, and Marion formations. In Oklahoma the latter three formations are grouped into the Stillwater.

In Kansas, these late Pennsylvanian and early Permian formations are typically marine fossiliferous shales and limestones, and this facies continues for a considerable distance into Oklahoma. After more than 20 years of work the Permian-Pennsylvanian boundary is not yet universally accepted even in this fossiliferous series.

The red shales of the Pontotoc suggest continental origin, and the color change in central Oklahoma which cuts across the Permian into the Pennsylvanian, suggests that land conditions appeared earlier in the southern area than in the northern. Could not this earlier appearance of land conditions have permitted a slightly earlier appearance of plants with a Permian facies in the Pontotoc, without indicating positively Permian age? Attention may be called to the well-known tendency of floras to precede faunas in many geologic periods.

As Morgan's *Walchia* is not identical with the typical Permian *W. pinniformis*, is there not some better evidence for drawing the Pennsylvanian-Permian contact at some other horizon?

[1]Robert H. Dott, *op. cit.*, p. 10.

[2]E. H. Sellards, "Fossil Plants of the Upper Paleozoic of Kansas," *Kansas Univ. Geol. Survey*, Vol. 9 (1908).

[3]David White, "Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section," *U. S. Geol. Survey Bull. 211* (1903).

POST-PONTOTOC UNCONFORMITY

Morgan stresses the presence of arkosic material in the Pontotoc as a characteristic of the group. It is not found lower, and none has been found above the base of Morgan's Asher formation, or of Unit 1 in Garvin County.[1] The sandstones above that point are different in character, and probably in origin. The shales are considerably brighter red. These facts are suggestive of change in deposition and of unconformity.

Evidence of overlap was found by the writer between the Pontotoc and Enid formations, in the area south of Wildhorse Creek, in Garvin County. Successively younger beds of the Enid seem to rest on Pontotoc conglomerates, shales, and limestones on the north side of the Arbuckle anticline. Birk[2] describes a similar unconformity around the west end of the Arbuckle Mountains.

The writer believes that the decided change in lithology, particularly the disappearance of the arkose, and the overlap, mark an important change in the sedimentary record and a pronounced unconformity which furnishes a better criterion in this area than the presence of the genus *Walchia*, and that the base of the Permian in south-central Oklahoma should be drawn at the base of Morgan's Asher in Pottawatomie County, and at the base of Unit 1 in Garvin County, and that no part of the Pontotoc should be included. This opinion was reached previously and independently by Birk.[3]

Anderson[4] disagrees with the writer's evaluation of criteria, and believes that the plant evidence is most dependable.

Morgan[5] states:

> . . the selection of a contact horizon, acceptable to everyone, between the Pennsylvanian and Permian will be difficult because the transition from Pennsylvanian to Permian was very gradual. My inclination, however, is to push the contact down rather than up, and I am, therefore, more in accord with the ideas of Dr. Anderson than with yours.

ENID GROUP

In Cleveland County, Anderson found a section of rocks which could be very readily subdivided. He was able to make a classification which

[1]Robert H. Dott, *op. cit.*

[2]R. A. Birk, "The Extension of a Portion of the Pontotoc Series Around the Western End of the Arbuckle Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 6 (September, 1925), p. 989.

[3]*Op. cit.*

[4]G. E. Anderson, letter to C. L. Cooper, dated April 15, 1930.

[5]George D. Morgan, letter of April 23, 1930.

agrees very well with the type area at the north. As the outcrops of the formations in McClain County are very poor, and difficult to differentiate, the Cleveland County markers can not be satisfactorily traced across McClain County into Garvin County. The correlations suggested by Anderson are approximately as shown in Table II.

TABLE II

SUBDIVISIONS AND CORRELATION OF LOWER ENID, AFTER ANDERSON
(Thicknesses shown in feet)

Garvin County		*McClain County*		*Cleveland County*	
Units 4-8	765	Hennessey	650	Hennessey	600
Unit 3 Unit 2 (upper)	130	Garber	200	Garber	200
Unit 2 (lower)	100	Wellington	100	Wellington	400
Unit 1 Pontotoc	140	Stillwater (including 250? feet of Konawa formation)	390	Stillwater	Absent

The thickness and general character of the Enid group in Garvin, McClain, and Cleveland counties are similar, and it seems that the character of the lithologic units composing the group should form the basis of correlations between the two areas, in the absence of traceable markers.

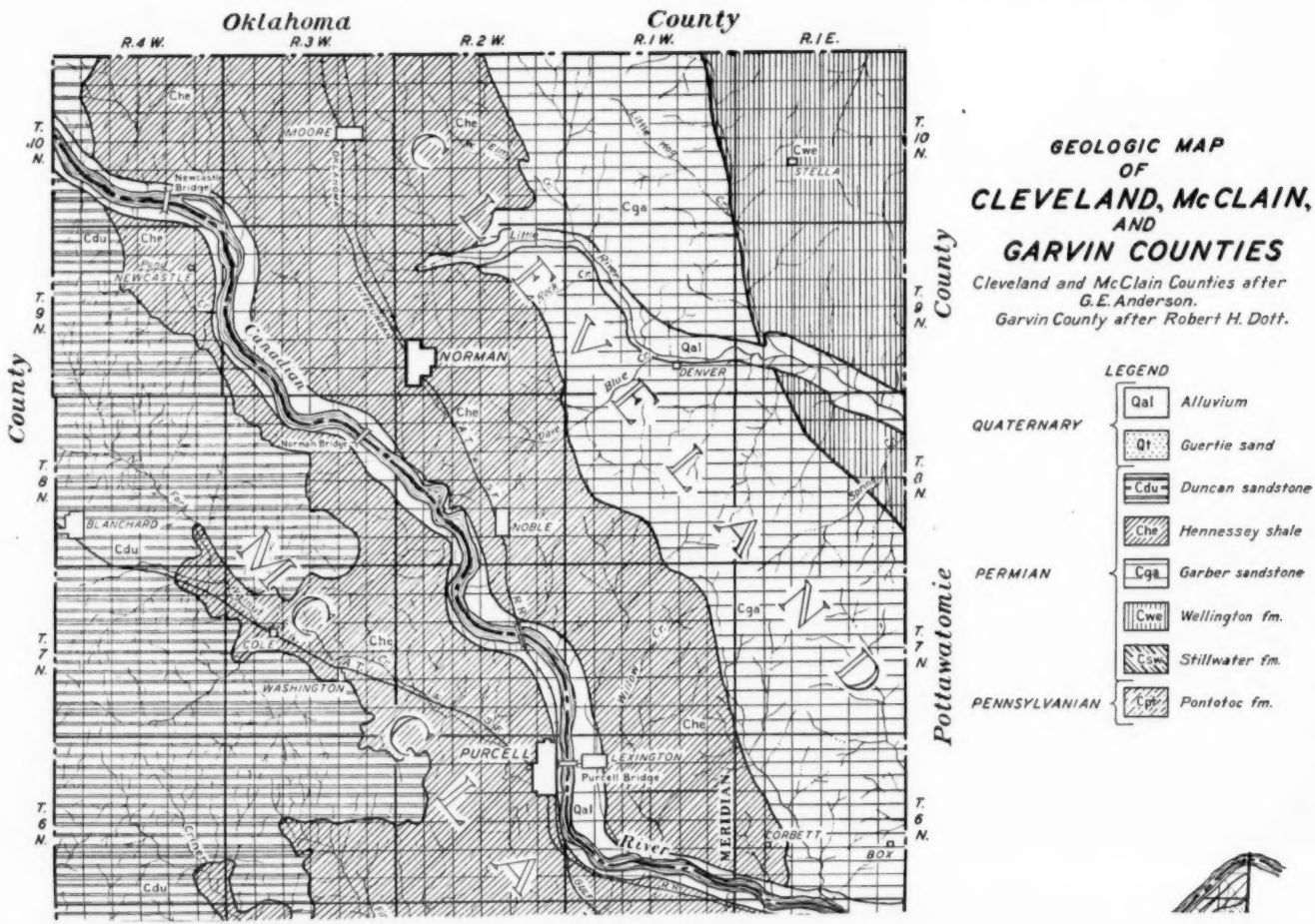
Since the two articles by Anderson and the writer were published, most of the differences as to correlation have been removed, and the following discussion presents the writer's present views, in which Anderson, in the main, concurs. Figure 2 shows the areal extent of the formations, as now understood, with a correction of contacts in Cleveland and McClain counties by Anderson.

Stillwater formation.—The outcrop of this formation is too far east to be present in Cleveland County. In McClain County, Anderson included in the Stillwater Morgan's Asher and the upper Konawa, making a total thickness of 390 feet.

Morgan[1] described the Asher formation as follows.

> At the bottom of this formation (Asher) is a thick series of coarse red sandstone that outcrops along the escarpment which extends from the river bridge south of Asher to the north edge of that town.

[1]George D. Morgan, "The Geology of the Stonewall Quadrangle," *Bur. of Geol. Bull. 2* (1924), p. 142.

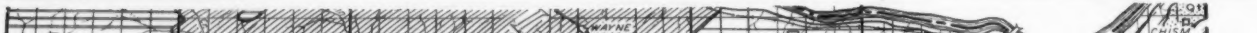


GEOLOGIC MAP OF CLEVELAND, McCLAIN, AND GARVIN COUNTIES

Cleveland and McClain Counties after G.E. Anderson.
Garvin County after Robert H. Dott.

LEGEND

QUATERNARY	Qal	Alluvium
	Qt	Guertie sand
PERMIAN	Cdu	Duncan sandstone
	Che	Hennessey shale
	Cga	Garber sandstone
	Cwe	Wellington fm.
	Cs	Stillwater fm.
PENNSYLVANIAN	Cp	Pontotoc fm.



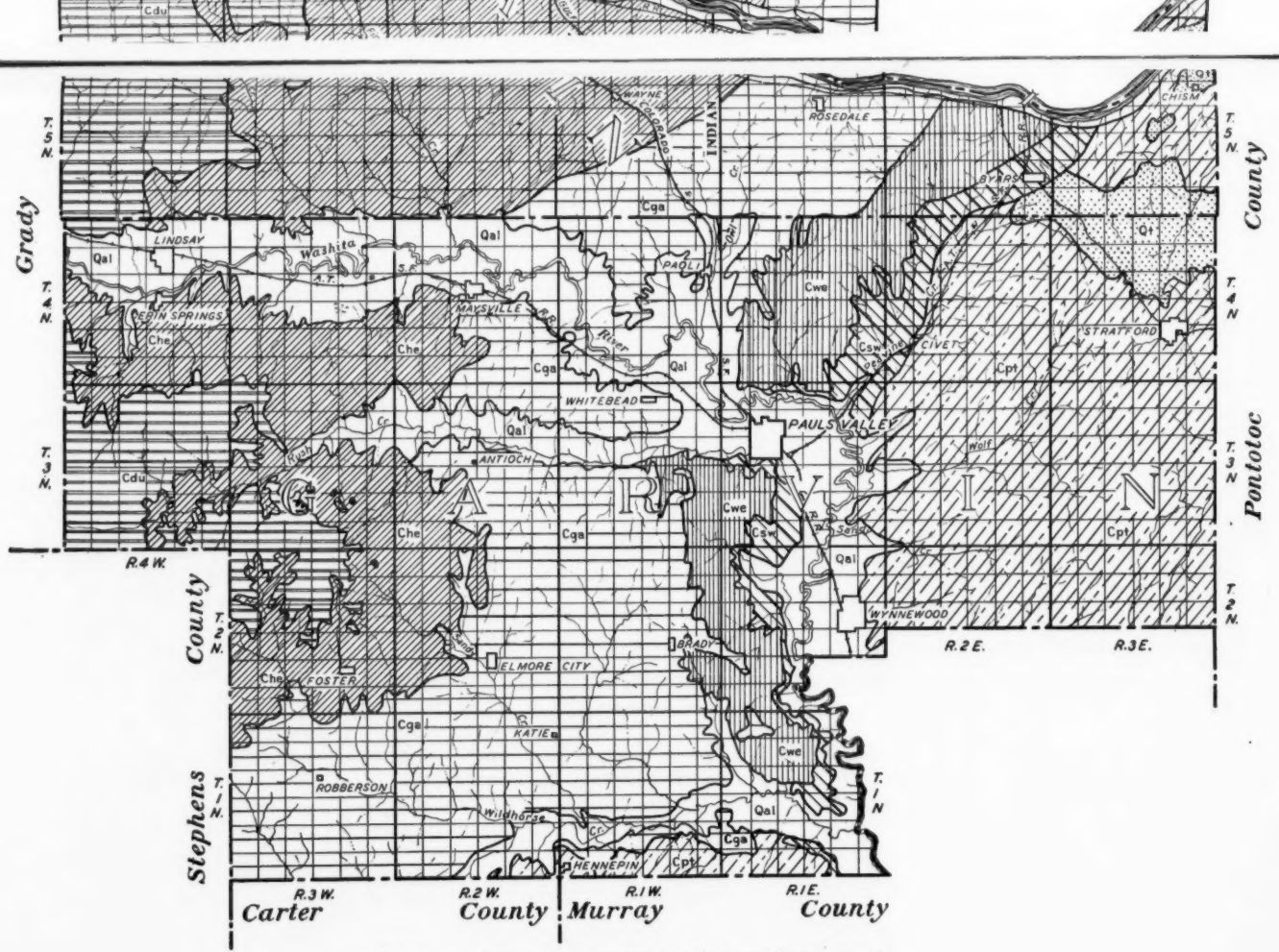


FIG. 2.—Geologic map of Cleveland, McClain, and Garvin counties.

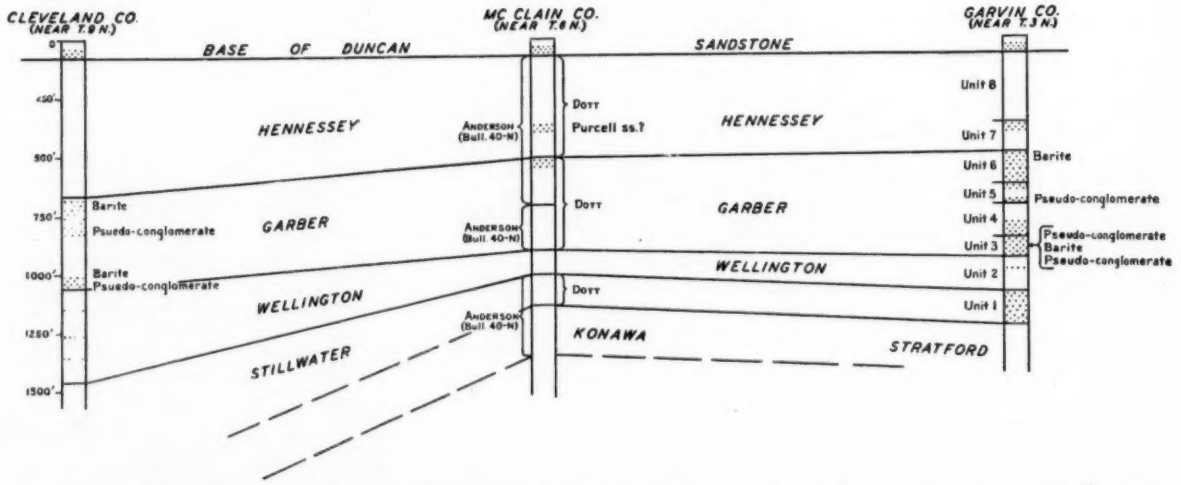


FIG. 3.—Comparison of measured sections in Cleveland, McClain, and Garvin counties. Bulletin references are to Oklahoma Geological Survey publications. Approximate length of section, 36 miles. Vertical scale in feet.

The lower limit of the Asher formation probably extends south and west beyond the edge of the Stonewall quadrangle before crossing Canadian River. The portion of the formation present in the northwest corner of the quadrangle is 250 feet thick. No upper limit is here defined.

Anderson[1] states:

At least the upper part of the Konawa and the Asher will be considered as time equivalents of the Stillwater formation . . . Unit 1 of Dott is included, and forms the top of the Stillwater formation in McClain County.

No measurements are available for the thickness of the basal Asher sandstone near Asher. Morgan evidently included some of the overlying shale in his 250 feet of section. From the height of the hill at the bridge south of Asher, it is probable that this basal sandstone has a thickness similar to that of Unit 1 in Garvin County, that is, 140 feet.

As Anderson and the writer do not agree about the base of the Permian, it follows that they disagree as to the base of the Stillwater. They agree, however, in placing the top of the Stillwater as the top of Unit 1.

Wellington formation.—Anderson[2] makes the following statement concerning the Wellington in Cleveland County.

The Wellington consists of red, gray, and black, massive, fine-grained sandstone, with interstratified shales. In Stella township, it forms rather prominent sandstone ridges covered with timber. Small open spaces are characteristic over the shale outcrops, suggestive of park landscape. . . . The formation grades laterally into more shale to the southeast in Pottawatomie County, on the north side of the Canadian River . . . The formation has . . . an approximate thickness of 400 feet.

And in McClain County:

. . the Wellington changes laterally from predominating sandstone in northeastern Cleveland County to shale in southwestern Pottawatomie and eastern McClain counties. It is the opinion of the writer (Anderson) that only the lower part of Dott's Unit 2 is in reality the time equivalent of the Wellington. It . . . has an approximate thickness of 100 feet. The surface outcrop in the county is characterized by gray shales, weathering into light gray soil.

Later, Anderson states:[3]

The Wellington-Garber contact I have not yet been able to outline with any degree of certainty. This is extremely difficult on account of the changing character of the materials along the strike. . . .

[1]G. E. Anderson, "Geology of Cleveland and McClain Counties," *Oklahoma Geol. Survey Bull. 40-N* (1927), p. 10.

[2]*Op. cit.*, p. 8.

[3]*Idem*, letter to C. L. Cooper, dated April 15, 1930.

In Garvin County, Unit 2 is composed of shale, with thin to locally massive sandstone, essentially similar lithologically to the Wellington in McClain County and less sandy than in Cleveland County. Its thickness is 145 feet.

It is essentially a lithologic and stratigraphic unit in Garvin County, separable from the formations above and below, and, in the opinion of the writer, should be considered the equivalent of Anderson's Wellington, despite its slightly greater thickness.

Garber formation.—In Cleveland County, the Garber is mostly sandstone. The lower part, according to Anderson:

> . . . is characterized by sandy shales, and interstratified, rather massive sandstones. In the lower 50 feet it is characterized by laminated sandstones and thin strata of pseudo-conglomerate . . . Above this is a zone of barite rosettes imbedded in sandstone strata. . . . The Hayward sandstone member (upper) is characterized by bright red sandstone strata with minor amounts of interstratified shale. The upper contact of the Garber is readily traced by its jack oak-covered surface in distinct contrast with the smoother prairie land on the Hennessey outcrop to the west . . .
>
> Barite rosettes are more abundant near the top of the sandstone, but are distributed . . . through the entire Garber formation . . . Pseudo-conglomerates similar to those found at the contact of Garber and Wellington are also found . . . about 100 feet below the top. . . . It has an approximate thickness in the county of 400 feet. . . .

In McClain County:

> The Garber formation is characterized by massive red sandstone lenses in the upper portion, grading into shale below. . . . The sandstone of the Garber is covered with jack oak timber at the Canadian River, by means of which it can be traced across the Canadian River at Pecan, Cleveland County, passing 1½ miles west of Rosedale and south to the county line through the southwest corner of Sec. 31, T. 5 N., R. 1 E. The top of the Garber should correspond to the top of Unit 3 . . . in Garvin County. Its thickness is approximately 200 feet.

The Garber formation is the key to the correlation of this whole series in Garvin County with the beds in the counties at the north. The greatest thickness of predominating sandstone beds is found in Units 3 to 6, inclusive, and it is this group which the writer now considers to be equivalent to the Garber sandstone. There is a striking similarity in lithology, sequence of beds, and thickness between these rocks and Anderson's Garber in Cleveland County.

The base of Unit 3 is marked by a prominent bed of pseudo-conglomerate overlain by barite rosettes. These are particularly well developed in the vicinity of Whitebead and in the north part of T. 4 N., R.

1 E., near the county line. This occurrence, so similar to that described by Anderson at the base of the Garber in Cleveland County, leaves little question in placing the Garber-Wellington contact at the top of Unit 2.

Pseudo-conglomerates occur at the middle and top of Unit 3, and barite rosettes occur at several horizons. Pseudo-conglomerate was found also in the lower part of Unit 5, and barite rosettes near the middle of Unit 6. The sandstones of this series (Units 3-6) are mainly bright red, in contrast to those of Unit 1, which are mainly red-brown. This group was called "red sandstones" by Miser.[1] Unit 6 is the top of the sandstone series, and has been eroded into rough topography, and is largely timber-covered. Its outcrop is in decided contrast to the prairie land on the west.

Attempts to trace the Garber-Hennessey contact across McClain County were attended with disappointment, as the Garber is mostly shale, or is covered by windblown sand from Washita River. Just east of the town of Paoli is an outcrop of massive sandstone which could easily be considered the top of the Garber, and was so considered by Anderson at the time of writing his report on Cleveland and McClain counties.

After studying the area south of Washita River, and comparing the entire section in that area with Anderson's section in Cleveland County, the writer was forced to the conclusion that the Garber-Hennessey contact must be considerably higher, and that the bed at Paoli was more nearly the top of Unit 3. Thus, the contact would trend southwest from a point 1½ miles west of Rosedale, to Sec. 19, T. 5 N., R. 1 E., thence west and south nearly to the middle of the north line of T. 4 N., R. 2 W. It may, therefore, be correlated with the top of Unit 6, south of Washita River. The trace of this contact is essentially parallel with that of the next higher Duncan-Hennessey contact.

Anderson recently stated:[2]

> I believe Dott is approximately correct in his tracing of the Garber-Hennessey contact through T. 4 and 5 N.

Such a correlation would add approximately 200 feet to Anderson's Garber in McClain County, giving a thickness of approximately 400 feet.

Hennessey formation.—In Cleveland County, the Hennessey shale[3]

> . . is characterized by predominating red shale, thin and frequently laminated. . . . Its lower 50 feet contain several thin, rather resistant sandstone

[1]Hugh D. Miser, "Geologic Map of Oklahoma," *U. S. Geol. Survey* (1926).

[2]G. E. Anderson, letter to C. L. Cooper, dated April 5, 1930.

[3]G. E. Anderson, "Geology of Cleveland and McClain Counties," *Oklahoma Geol. Survey Bull. 40-N* (1927), p. 9.

strata which form characteristic flat-topped hills along the east border of the prairie. . . . It has an approximate thickness of 600 feet in the county. . . . It is predominantly shale in McClain County, with a few sandstone lenses which rapidly grade laterally into shale . . . The most notable of these is the sandstone bluff on the south side of the Canadian River, immediately north of Purcell. Another such sandstone lens forms a rather high bluff in Sec. 21, T. 8 N., R. 2 W., on the north side of the Canadian, and still another, though less prominent, two miles west of Purcell, on the north line of Sec. 16, T. 6 N., R. 2 W., all these apparently at different stratigraphic horizons within the shale . . . The Hennessey forms a broad belt, many miles wide, and has a uniform thickness of approximately 650 feet.

As the Garber-Hennessey contact in McClain County is now thought to be west of, and stratigraphically higher than, the contact mapped by Anderson, the thickness of the Hennessey would be less, probably about 450 feet.

In Garvin County, Units 7 and 8 are predominantly shale, with several sandstone horizons, particularly at the base and middle of Unit 7, at the base and top of Unit 8. Those at the base of Unit 8 are persistent, and can be traced nearly across the county. They strongly resemble the sandstones mentioned by Anderson as occurring at the base of the Hennessey in McClain and Cleveland counties. They probably could be recognized north of Washita River, in McClain County, and may lie at the horizon of one of the sandstone beds mentioned by Anderson. Thin, white beds of sandstone occur in the red shale, near the top of Unit 8, giving a banded appearance. Frank C. Greene suggests that these may lie at the approximate horizon of the Merkel dolomite of north-central Texas.

The topography is that of gently rolling prairie land. The thickness of the two units is about 430 feet. Table I of *Oklahoma Geological Survey Bulletin 40-K*[1] is in error as to the thickness of Unit 8. It should read 300 feet instead of 500 feet.

The lithologic character, gently rolling topography, vegetation, and the stratigraphic position between two massive sandstones leave little doubt as to the equivalence of Units 7 and 8 with Anderson's Hennessey.

CONCLUSIONS

The writer proposes to subdivide and correlate the Red-beds in Garvin County which lie between the Pontotoc formation and the Duncan sandstone, shown in Table III.

[1]Robert H. Dott, "Geology of Garvin County," *Oklahoma Geol. Survey Bull. 40-K* (1927), p. 20.

TABLE III

SUBDIVISIONS AND CORRELATION OF RED-BEDS IN GARVIN COUNTY
(Thicknesses shown in feet)

Garvin County			*McClain County*		*Cleveland County*	
Unit 8, Unit 7	Shale	430	Hennessey shale	450	Hennessey shale	600
Unit 6, Unit 5, Unit 4, Unit 3	Main sandstone formation	420	Garber sandstone	400	Garber sandstone	400
Unit 2	Shale	145	Wellington formation	100	Wellington formation	400
Unit 1	Sandstone	140	Stillwater formation	140	Absent	

DISCUSSION

SHERWOOD BUCKSTAFF, Pauls Valley, Oklahoma (written discussion received, July 11, 1931): Mr. Dott's revision of earlier correlations in Garvin and adjacent counties is another step toward the solution of early Permian stratigraphy in southern Oklahoma. The writer, however, considers that one of his correlations, that of the Garber as equivalent to Units 3 to 6, is not proved. The correlation, as he states, is based largely on thicknesses and lithologic similarities. Lithologic similarity of red beds, deposited under rapidly changing conditions of sedimentation, is a dangerous criterion for correlation. The sequence of sandstones, shales, pseudo-conglomerates, and barite rosettes is, in the writer's opinion, merely a repetition, in two areas, of sediments commonly occurring and not a proof of simultaneity. The structural evidence is not compatible with this correlation. Mr. Dott's Garber-Hennessey contact across T. 5 N. is obviously arbitrary, connecting two areas of sandstone; but it is at variance with the true strike of the formations as revealed by detailed mapping in the west half of T. 5 N., R. 1 E. and the southern part of T. 5 N., R. 1 W. Furthermore, it transgresses the strata from the top of Unit 3, in the northwest part of T. 5 N., R. 1 E., to the top of Unit 6 in the center of T. 4 N., R. 2 W. The parallelism between this contact and the overlying Duncan-Hennessey contact, remarked by Mr. Dott, is not a true structural parallelism. The Duncan-Hennessey contact, across the area involved, becomes progressively lower topographically as it is traced southwestward into the Washita River valley, and the strike of the contact is more east of north than the strike of the beds. The Garber-Hennessey contact as shown by Mr. Dott's map rises from the South Canadian River Valley to the top of the topography and drops into the Washita Valley unaffected by the topography. If this contact were traced to conform with the topography, the parallelism of the two contacts would vanish.

As Mr. Dott notes, the "Garber" in T. 5 N., R. 1 W. is largely shale. The top of the sandstones of Unit 3, south of South Canadian River, seems to be

100 feet or more lower than the top of the accepted Garber north of the river. Evidences of structural irregularity being lacking across the river, this discrepancy must be due to gradation of the upper sandstones of the Garber to shale. Such a gradation is in accord with the greater thickness, greater sand content, and closer proximity to the source (not necessarily the ultimate source, but the locus of maximum deposition of sediments) of the Garber farther north. Mr. Dott assumes that as the shales grade back to sandstones, south of Washita River, the tops of the two sandstone zones are equivalent. There is no logical basis for this assumption, as the sandstones south of Washita River, becoming laterally more shaly northward and more sandy southward, almost certainly come from some source southeast of the area, and are not necessarily contemporaneous with the Garber sandstones. Detailed mapping of zones and thicknesses indicates that the top of the sandstone south of Washita River (top of Unit 6) is approximately 160 feet higher stratigraphically than the top of the Garber north of South Canadian River. Consequently, the writer considers that the true Garber-Hennessey is not as shown by Mr. Dott's map, and, by the nature of the sedimentation, can not be traced by lithology across Garvin County.

ROBERT H. DOTT, Tulsa, Oklahoma (written discussion received July 13, 1931): An acceptance of any opinion relative to red-bed stratigraphy in south-central Oklahoma must depend on an agreement as to criteria.

All workers would accept the absolute and unquestioned tracing of some key bed. If the top of the Garber as defined in Cleveland County could be definitely traced across McClain County into the units of Garvin County, the stratigraphic position of that horizon in the Garvin County units could be established to the satisfaction of everyone.

The broad Washita valley in northern Garvin County alone makes such tracing impossible. Lacking such irrefutable evidence, other criteria must be applied, and stratigraphic sequence, lithologic similarity, and similar thicknesses seem to be of as great value in this type of beds as any other. Certainly it can not be said that they fail in the area north of Canadian River, between Cleveland and Oklahoma counties, where actual tracing can be done.

From Purcell to Oklahoma City a thick, dominantly sandstone series, cropping out in a terrane of rugged, jack oak-covered hills, is overlain by a likewise thick shale, whose outcrop is characteristically treeless, and in whose basal 100 feet occur several persistent sandstone ledges. These criteria are referred to repeatedly as marking the Garber-Hennessey contact in those counties. If they hold for a distance of 40 miles along the strike, is it unreasonable to assume that an almost identical sequence in Garvin County, 12 miles farther south, marks the same contact?

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LOWER PLIOCENE IN SANTA MARIA DISTRICT, CALIFORNIA[1]

WILLIAM W. PORTER II[2]
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ABSTRACT

The Miocene-Pliocene geological history of the Santa Maria district, Santa Barbara County, California, is discussed. The Sisquoc formation, a lower Pliocene formation, is described, and it is shown that the upper "Harris" formation in the Purisima Hills is also lower Pliocene. Continuous diastrophism during Pliocene time is discussed. Its divergent effects upon marginal and central areas of the Pliocene basin are indicated by the partly conformable and partly unconformable contact.

INTRODUCTION

During the writer's field work in the Santa Maria-Santa Ynez embayment, Santa Barbara County, California (1929-1931), the collected paleontological material was studied by Mrs. D. A. Castle and Paul P. Goudkoff. The age determinations of the lower Pliocene were made by Mrs. Castle[3] on the basis of *Mollusca*. Correlations throughout the district by means of microfauna were made by Goudkoff. The writer here wishes to express thanks to Mrs. Castle and Dr. Goudkoff for their helpful collaboration, and to E. L. Ickes and the Western Gulf Oil Company for permission to publish these results.

RESUMÉ OF STRATIGRAPHY

Vaqueros formation (lower Miocene).—Before deposition of the Vaqueros formation, there was an important period of folding and erosion. As a result, Vaqueros sandstone was deposited upon Franciscan, Cretaceous, Eocene, and Oligocene. The Vaqueros is irregularly distributed, as parts of the Santa Maria-Santa Ynez region seem to have remained above water as islands or peninsulas during Vaqueros time.

Temblor formation (middle Miocene).—The Temblor is represented by a thickness ranging from almost nothing to a few hundred feet, of gray to grayish brown clay shale. Near the southerly border of the San

[1]Manuscript received, June 1, 1931.

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[3]Dorothy A. Castle, unpublished manuscript and personal communications.

FIG. 1.—Sketch showing general location of area.

Rafael Mountains it is finely arenaceous, but contains a distinctive Temblor microfauna.[1]

Monterey formation (*middle Miocene*).—General submergence followed Temblor time, and uniform regional Monterey deposition occurred. At that time were deposited flinty and siliceous shales similar to the Monterey of other parts of the state.

Santa Margarita formation (*upper Miocene*).—Santa Margarita occurs without depositional break above the Monterey. As its nature varies locally, and as it is closely related to the Sisquoc formation, it is discussed more fully in another part of this article.

Sisquoc formation (*lower Pliocene*).—This comprises silts, sandstones, and diatomites. It is described later.

Foxen formation (*middle Pliocene*).—This formation was described by C. F. Tolman,[2] and the use of the term *Foxen* by the writer is essentially the same as Tolman's. The Foxen formation is younger than the lower Pliocene Sisquoc on which it lies, and it is tentatively referred to the middle Pliocene. Above it, in some localities conformably and in

[1]Determination by Paul P. Goudkoff.

[2]C. F. Tolman, discussion at joint meeting of the LeConte Club and the Cordilleran Section of the Geological Society of America, at Stanford University, January 29, 1926. Abstract in *Geol. Soc. Amer. Bull. 38* (1927).

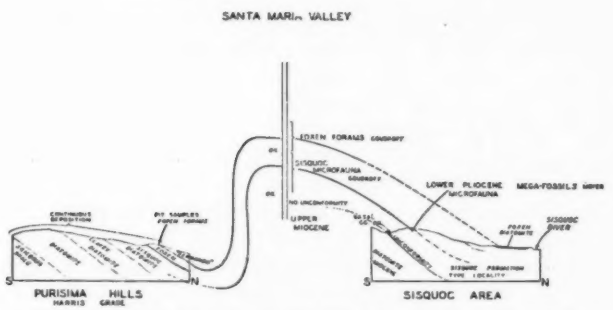

FIG. 2.—Diagrammatic representation of correlations. Field sections in Purisima Hills and Sisquoc area are diagrammatic and not to scale. Correlation of areas with vertical column of Santa Maria Valley is shown by connecting curves. Santa Maria Valley section is known only from well cores. Data obtained from following wells: O. C. Field Gasoline Corporation's Bradley No. 1 (formerly the System well), O. C. Field's Norswing No. 1, Garlipp and associates' Donovan No. 1, Keystone *et al.* Paderewski No. 1, and Western Gulf Oil Company's Bradley-B No. 1.

others unconformably, lie the fossiliferous yellow sandstones generally known as "Fernando."

The Foxen is a clay shale formation varying locally to diatomite. It is characterized by a distinctive microfauna which has been found in many well cores and in pit samples from surface outcrops on the Harris Grade road. An easily accessible outcrop is on the north side of the Purisima Hills near the foot of the Harris Grade road which connects Lompoc with the Coast Highway at Harris Station. The formation is exposed in cuts on the west side of the creek just south of the small bridge about a mile south of Harris Station. Foxen diatomite can be observed in the Solomon Hills near the summit of the Howard Canyon road, and above the Sisquoc formation south and east of the Sisquoc Ranch house.

The thickness ranges from 40 feet in surface sections in the Solomon Hills to several hundred feet in wells in the Santa Maria Valley. The formation is approximately 600 feet thick on the Harris Grade road.

Other formations.—Beds older than Miocene and younger than Foxen Pliocene are not mentioned, as they have no important bearing on the substance of this article.

SANTA MARGARITA FORMATION

The Santa Margarita formation occurs in the Casmalia Hills; in the San Rafael Mountains between Foxen Canyon and Sisquoc River,

and near Zaca Lake; in the Purisima Hills; and at depth under the Santa Maria Valley. The Santa Margarita is represented by a different lithologic facies in each of these localities, showing that the period of widespread and relatively uniform Monterey deposition was gradually closed by locally operative diastrophism.

San Rafael Mountains.—From near the United States Geological Survey Bench-Mark Elevation 671 in Foxen Canyon eastward approximately 4 miles, the siliceous Monterey shale is overlain by fairly pure diatomite. The contact is gradational through 10-40 feet stratigraphically in some places. In other places, the siliceous shale-diatomite contact is sharp. Toward the east the diatomite becomes lenticular and grades laterally into hard, non-organic, ordinarily well bedded, nodular, conchoidal, in places finely arenaceous, gray-brown shale. In the Sisquoc Grant near the southwesterly grant line, and a mile west of Asphaltum Creek, the fairly pure diatomite grades within ¼ mile into the hard brownish shale. An upper Miocene microfauna was found in the hard brown shale farther east in the Sisquoc Grant, on La Zaca Creek.

Casmalia Hills.—In the Casmalia Hills in the area of the Casmalia oil field, is a complete section from the upper Pliocene, exposed in Schumann Cut along the railroad, down to the Monterey, which occurs at depths of approximately 800 feet in the oil wells, and on the surface west of the town of Casmalia. Part of this section must, therefore, be the time equivalent of the Santa Margarita. On the basis of lithology, the writer has correlated the decidedly platy, hard, siliceous shale (the "hard brown" of the oil field) with the upper Monterey, because this lithology has been found to be typical of Monterey in the general area. Above the platy siliceous shale is approximately 1,000 feet of section which consists principally of gray clay shale grading into impure diatomaceous shale near the top. The clay shale is characterized by a splintery fracture, and sheeting or fracture planes thinly incrusted with limonitic material.[1] The formation occupies the area of low undulating hills along the railroad south of Schumann Cut, and at the west end of the Casmalia oil field. This shale lying above the platy siliceous shale, and below the Pliocene diatomite of Schumann Cut, is considered by the writer to be Santa Margarita, though Santa Margarita fossils are absent.

Santa Maria Valley.—Well cores show a gradation from Pliocene fine muddy silts and silty sands down into Miocene fine muddy silts and silty sands with here and there interstratified hard brown clay shale

[1]Splintery fracture and sheeting planes are also characteristic of the Santa Margarita formation of the Point Concepcion area, Santa Barbara County, California.

and siliceous shale; or a change from Pliocene siltstone to upper Miocene shale. One well (O. C. Field's Bradley No. 1, formerly the System Oil Company well) cored a sharp contact between fine gray siltstone and "poker chip" Miocene shale, there being positively no evidence of unconformity. The change from Pliocene to Miocene in the Valley is either an abrupt or a transitional change in type of deposition without unconformity.

SISQUOC FORMATION

The oldest Pliocene formation in the area has been named the Sisquoc formation, and is of lower Pliocene age. The formation is named from its well exposed section on the Sisquoc Ranch, on the south side of Sisquoc River, in the Sisquoc Grant.

At the base of the formation is a pebbly conglomerate with sandstone which is partly impregnated with dry oil or tar. These beds are exposed on the Sisquoc-Tinaquaic line fence, approximately 6 miles east from the northwest corner of the Tinaquaic Grant. From the basal sand and conglomerate northward a good section is exposed, and it was here that plane-table measurements were made, pits dug, and most of the collecting done.

In this area the formation is 1,150 feet thick, and can be divided into two parts at two thin iron-stained conglomerate stringers approximately 600 feet above the base.

The lower 600 feet contains two parts. The basal 40 feet consists of pebbly conglomerate and sandstone,—more sandy than conglomeratic,—containing the dry oil or tar. This is probably the equivalent of the producing horizon in the East Cat Canyon oil field. Most of the remainder of the lower part is fine and friable, hence not fully exposed, though some fossil-bearing horizons crop out. There occur beds of shaly diatomite containing also fish remains, radiolarians, and sponge spicules, and at one place, volcanic glass; but most of the section is a fine muddy, silty, friable, gray sandstone. The bountifully fossiliferous beds occur 500 feet above the base, and contain the plentiful mulluscan fauna which is correlated with the lower Jacalitos formation of the Fruitvale area in the San Joaquin Valley.[1] These same beds contain microfaunal assemblages equivalent to those found in cores from wells in the Santa Maria Valley at depths ranging from 4,000 to 5,000 feet. The presence of microfauna associated with known *Mollusca* definitely establishes the Pliocene age of the microfauna whose age has heretofore been questionable.

[1]Dorothy A. Castle, *op. cit.*

The upper part of the formation consists in general of 550 feet of fine, friable, ordinarily ferruginous, fossiliferous sandstone interbedded with finer material. Near the top of the section is a very fossiliferous sandstone. The most conspicuously fossiliferous part is 15 feet thick. Similarity of this horizon to cores from a depth of 1,500 feet in Riverside and Gilmore's Williams No. 1, in East Cat Canyon, suggest that it is probably part of the "tar sand" zone of the East Cat Canyon oil field. These upper sands of the Sisquoc are also exposed on the south side of Foxen Canyon in the southeast quarter of the Tinaquaic Grant. They occur in patches beneath the Foxen diatomite, which is the same diatomite exposed on the axis of the Gato Ridge anticline on the Howard Canyon road. The diatomite is thus above a considerable thickness of Pliocene sandstones and silts, and is possibly middle Pliocene in age, though lithologically it is in places indistinguishable from Miocene diatomite. The Sisquoc section on the Sisquoc Ranch is also overlain by Foxen diatomite.

SANTA MARGARITA AND SISQUOC FORMATIONS, PURISIMA HILLS

In the Purisima Hills, particularly along the highway from Lompoc to Santa Maria (which joins the Coast Highway at Harris Station) is a well exposed section of various grades of diatomite.[1] This section is the north flank of the Purisima anticline, and is well exposed from the axis of the anticline on the road on the south side of the hills, north to the north foot of the hills. The highest strata of the section are freshwater beds, and fossiliferous, soft yellow Pliocene sandstones called Fernando by Arnold.[2] In this article, the writer is concerned not with these beds, but with the Foxen, which underlies them, and with the diatomite section under the Foxen.

As already mentioned, the Foxen on this Harris Grade road is approximately 600 feet thick, and contains a distinctive microfauna. Beneath the Foxen, without break in deposition, is the diatomite section, which is well exposed from the base of the Foxen south to the axis of the Purisima anticline. Near the axis of the anticline the diatomite grades into brittle, siliceous shale. This brittle, platy, siliceous shale is either Monterey, or it is a transition immediately above the Monterey, and, if either, it is clear that the occurrence represents continuous deposition

[1]This diatomite section, exposed on the Harris Grade road, is sometimes referred to as "Harris." The term "Harris" is in more or less general use among geologists, but it is not specifically definitive.

[2]Ralph Arnold, *U. S. Geol. Survey Bull. 322* (1907).

from the Monterey to the diatomite section exposed on the road. The Purisima Hills section, therefore, along the Harris Grade road, may be considered to represent continuous deposition from the Monterey to the top of the Foxen, or from middle Miocene to approximately middle Pliocene. Therefore, the section exposed, 2,300+ feet, represents the time equivalent of the Santa Margarita and Sisquoc formations.

The diatomite section beneath the Foxen can be divided into three units as follows.[1]

Overlain by Foxen

Top
1. Medium pure diatomite on which grows scrubby brush. Thickness estimated at 750 feet
2. Clayey diatomite which weathers to form a fairly smooth undulating surface. Estimated at 500 feet
3. Medium pure diatomite similar to No. 1. This is also characterized by a growth of scrubby brush. Estimated at 1,000 feet

Bottom

Grades down into Monterey

As these three units are the time equivalents of Santa Margarita and Sisquoc, and as the overlying Foxen is well identified by microfauna, it follows that at least the upper part of the diatomite section must be the Purisima Hills correlative of the Sisquoc formation. This can be stated regardless of the absence of Sisquoc fauna from the Harris Grade diatomite, because there is no field evidence of a hiatus, and wells in the Santa Maria Valley, after penetrating beds definitely correlated with the Foxen of Harris Grade, continue downward into microfaunal zones of the Sisquoc formation. On the basis of these data, there being no hiatus, the next lower formation below the Foxen must be Sisquoc.

With the fact established that the upper part of the Harris Grade diatomite section is Sisquoc, and the lower part Santa Margarita, it is nevertheless an exceedingly difficult matter to place the base of the Pliocene, but this very difficulty is evidence of the type of diastrophism that closed the Miocene.

MONTEREY-SANTA MARGARITA DIASTROPHISM

At the close of Monterey time, locally active diastrophism operated in such a way as to produce different facies (hard brown shale and diatomite north of Foxen Canyon; clay shale near Casmalia; siltstone and shale in the Santa Maria Valley; and diatomaceous shale in the Purisima Hills) of the Santa Margarita formation without seriously interrupting deposition.

[1]The figures of thickness are not precise.

SANTA MARGARITA-SISQUOC DIASTROPHISM

The diastrophism at the close of the Miocene period was characterized by emergence and tectonic activity along orogenic zones. Parts of the San Rafael and Santa Ynez mountains were elevated above Miocene sea-level, while the area of the Purisima Hills remained relatively quiescent. The mountain masses, having emerged from the Miocene ocean, became the partly encompassing shores of a Pliocene sea, and the residual Miocene waters became a Pliocene basin. As a result of this type of uplift, deposition in the central parts of the basin continued without interruption, and with only such changes in type as were caused by the influence of newly made shores, and minor warpings in the basin. In contrast, marginal areas were the locale of more severe tectonic activity and probably intermittent erosion and re-submergence. The results of this process are: the continuous deposition from Monterey to upper Foxen in the Purisima Hills; the unconformity overlain by a basal Pliocene conglomerate on the Sisquoc Ranch on the south border of the San Rafael Mountains; and the variation in lithology of correlative lower Pliocene strata throughout the district.

The rise of the San Rafael Mountains was not a rapid process, but was caused by continued or spasmodic movement during all Pliocene time. The similarity of Sisquoc fauna to lower Jacalitos fauna suggests that a waterway between the Santa Maria district and the San Joaquin Valley remained open well into lower Pliocene time. Relatively small thicknesses of strata on anticlines, and greater thicknesses in synclinal areas suggest that submarine folding or faulting, or both, operated in the basin during Pliocene deposition, and that, in comparison with the Miocene, the Pliocene was a period of considerable diastrophic activity. In the Purisima Hills an unconformable buttressed overlap of approximately 2,000 feet occurred, not at the Miocene-Pliocene contact, but within the Pliocene at the end of Foxen deposition.

CONCLUSIONS

A complete Miocene-Pliocene section occurs in the Santa Maria-Santa Ynez area, but within this area each of the formations is represented by one or more lithologic facies. The various facies have been produced by the mobility of the area when subjected to influences of diastrophism. The area was neither uplifted nor depressed as a unit in upper Miocene and Pliocene time, but was subjected to the effects of variously localized movement resulting in a variety of sedimentary

types according to the nature and magnitude of diastrophism at any particular place.

Local movements continued through the Pliocene period and influenced thickness and lithology of all of the Pliocene formations.

The principal movements at the end of the Miocene period occurred on the periphery of the Pliocene basin, causing marginal unconformity, but permitting continuous deposition in central areas.

The Sisquoc formation of lower Pliocene age occupies a large surface area and has a considerable subsurface extent in the Santa Maria-Santa Ynez district. It is represented in the Purisima Hills by an upper part of the diatomite section, exposed on the Harris Grade road.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 145-152, 1 FIG.

MICHIGAN STRUCTURAL BASIN AND ITS RELATIONSHIP TO SURROUNDING AREAS[1]

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ABSTRACT

The Michigan basin is a broad structural and sedimentary basin probably originating in pre-Cambrian time. It is slightly rectangular in form, trending northwest and southeast, with its deepest point near the center of the southern peninsula of Michigan. It extends approximately 450 miles east and west, and almost the same distance north and south. The rocks dip toward the center at the rate of 30-35 feet per mile. Its sedimentary and structural history is closely related to the large positive elements of the Cincinnati, Kankakee, and Wisconsin arches. These features are outlined on a structural map contoured on the Trenton limestone. Folds within the Michigan basin have a persistent northwest-southeast parallel trend and may be traced through a distance of 40-60 miles. Their origin is believed to be closely related to the early history of the basin itself, being controlled by trends of folding or lines of structural weakness which existed in the basement rocks.

INTRODUCTION

Much material has been published on the broader structural features of central and eastern United States, but very little has been said regarding the Michigan basin and its relationship to some of the better known surrounding tectonic elements. As most of the area within the Michigan basin is covered with a mantle of glacial drift, the older geologists were hampered in their interpretation of its true form and in their study of the minor or local folds. The addition of deep-well data during the past few years has furnished considerable helpful information bearing on many of the puzzling problems of structure and stratigraphy. The same data have suggested many other problems of a complex nature which will require many additional data before a thorough explanation can be reached. The form, size, and position of the basin have changed from one period of deposition to another. This can be fairly well depicted by a series of isopach maps constructed from deep-well data, although there are many areas in which little information is available. There is a suggestion of an old intermittent barrier in northeastern

[1]Manuscript received, June 23, 1931.

[2]Hudnall and Pirtle, consulting geologists. Present address, Box 940, Tyler, Texas.

Michigan which existed during Traverse time,[1] perhaps longer, and there may be others. One of the most interesting and important problems from an economic viewpoint includes the origin and nature of the folding within the basin. Since Michigan has become an oil and gas state of some importance, much will be found out in the next few years regarding these problems. It is the purpose of the writer to discuss briefly the broader structural relationship of the Michigan basin and what is now known concerning the structures within the basin and their possible origin.

The writer wishes to acknowledge his indebtedness to W. A. Thomas of The Pure Oil Company, and R. B. Newcombe of the Michigan Geological Survey, who materially assisted in furnishing data for the structural map; also to C. W. Cook, of the University of Michigan, who reviewed the manuscript.

REGIONAL STRUCTURE

The regional structure of the Great Lakes area and the related tectonic elements of the Michigan basin are shown by means of contours on the accompanying map. This map embraces one of the most interesting areas of the United States, outlining the Appalachian, Michigan, and Eastern Interior coal basins, together with the related positive elements of the Wisconsin arch, Kankakee arch, Cincinnati arch, and the La Salle anticline. These great elements are related more or less to the Michigan basin and its structural features, and were closely associated with it during its depositional and structural history. A more thorough understanding of this relationship will help to solve many of the puzzling problems of structure and stratigraphy.

The structural map outlining these features is contoured with an interval of 500 feet on the Trenton limestone of Middle Ordovician age. The Galena limestone was used as a key in Iowa, northern Illinois, and Wisconsin and is the nearest equivalent of the Trenton in this area. The map is principally based on deep-well records and data published by the different state and Canadian surveys, and is a composite picture of the basin and adjacent areas. The Trenton, one of the most uniform horizons in this area, may be reached at most places with the drill. However, in the center of the basin, it was necessary to project the structure as compiled from Dundee well records because of lack of Trenton control. An allowance was made for the gradual rate of thickening of beds toward the center of the basin, but the form and trend of the minor folds are as

[1]Erwin R. Pohl, "The Middle Devonian Traverse Group in Michigan," *U. S. Natl. Museum*, Vol. 76, Art. 14, pp. 1-34.

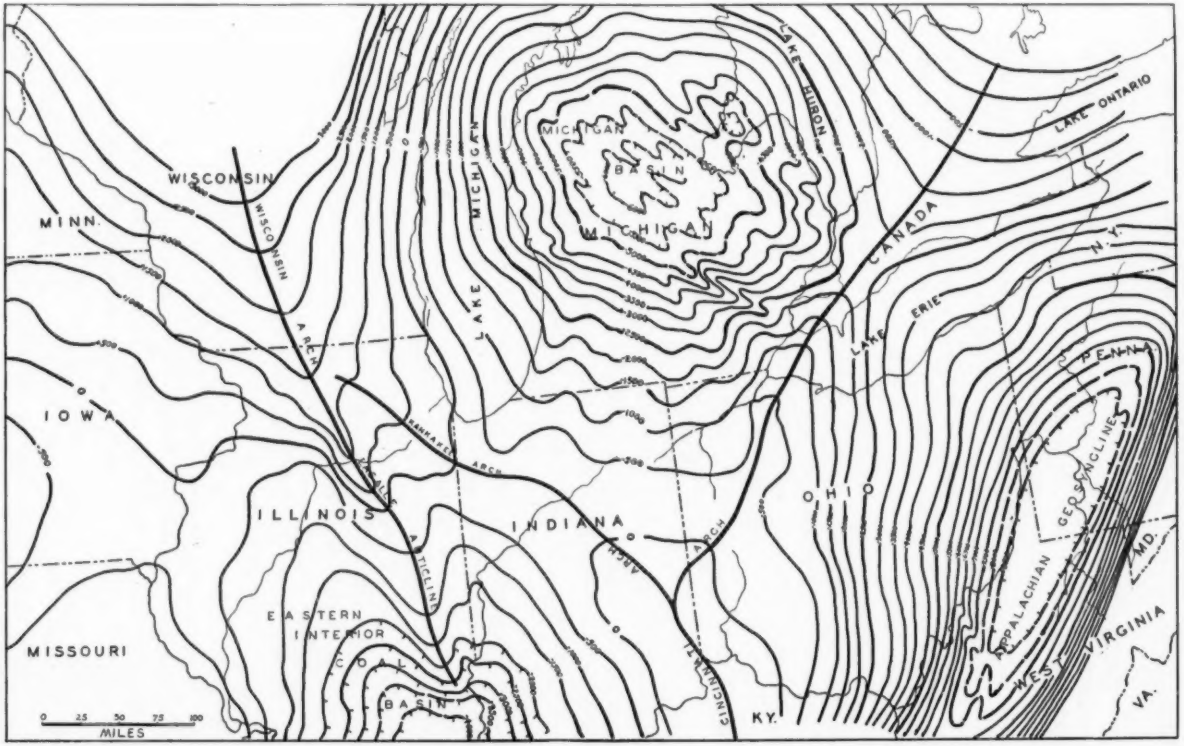

FIG. 1.—Regional structure of Michigan basin and adjacent areas, contoured on Trenton limestone. (By George W. Pirtle.)

contoured on the Dundee. This does not take into consideration the possibility of any major unconformities which may exist on the lower beds beneath the Middle Devonian. In the Appalachian geosyncline and the Eastern Interior coal basin, all the available deep-well records were used and contours were drawn on the deepest horizons possible, and projected to the Trenton.

The Trenton is approximately 6,000 feet below sea-level in the Michigan basin, about 4,000 feet below in the Eastern Interior coal basin, and perhaps 11,000 feet below in the Appalachian geosyncline.

The Michigan basin is bordered on the south and east by the Cincinnati arch, which bifurcates in the vicinity of Richmond, Indiana, one prong extending northeastward into Ontario and the other northwestward toward the southern end of Lake Michigan. On the southwest it is bordered by the Kankakee arch, which is continuous with the Cincinnati arch and is seemingly related to both the Cincinnati and Wisconsin arches. The western limit of the basin is the Wisconsin arch, which is a broad uplift trending southeastward, the continuation of which forms the La Salle anticline, the principal positive feature of Illinois. On the north of the basin the rocks rise rapidly to the intensely folded pre-Cambrian series of the Lake Superior region, which are fractured and broken by large faults. The Michigan basin is seemingly related, and at one time was possibly continuous with the Lake Superior geosyncline, which follows the lake in a half-moon shape around the upper peninsula of Michigan, possibly becoming continuous near the north tip of the lower peninsula.

Wisconsin arch.—The Wisconsin arch is a broad fold, with an axis trending N. 20° W., extending from central Wisconsin southeastward into Illinois. This fold probably follows a line of deformation of the pre-Cambrian mountains, which were base-leveled before Paleozoic time, leaving a few monadnocks which still characterize the topography of parts of central Wisconsin. These old mountains were large, as is revealed from the structure of the extremely metamorphosed rocks. They were perhaps similar to the Alps, the Alleghenies, or the Rockies.[1] Following the peneplanation of the pre-Cambrian mountains, the Paleozoic sea encroached upon the land, but the St. Croix series, of Cambrian age, seems to be the only formation deposited throughout the whole area of the arch.[2] The later formations now occur only on the flanks of the arch

[1]Samuel Weidman, "Geology of North Central Wisconsin," *Wisconsin Geol. Survey Bull. 21* (1907).

[2]Weidman and Schultz, "Water Supplies of Wisconsin," *Wisconsin Geol. Survey Bull. 35* (1915).

and it is possible that they never extended over all its axis. However, the part of the arch south of Baraboo was covered by Ordovician and Silurian rocks, and the early Ordovician rocks were undoubtedly deposited as far north as the Wisconsin Rapids. The principal divisions are all separated by major unconformities and undoubtedly there was intermittent movement along the old axis during all Paleozoic time. The Hamilton of the Devonian period is the last division of the Paleozoic represented in Wisconsin and the whole area has evidently been above land since that time.

Kankakee arch.—The Kankakee arch is a relatively small uplift, trending N. 45° W. in northeastern Illinois and northwestern Indiana. It connects the Wisconsin and Cincinnati arches, but it is believed to be more closely related to the Wisconsin arch in age, and probably marks the southeastward continuation of the pre-Cambrian deformation. This line of deformation perhaps controlled the course of the west prong of the Cincinnati arch, and it is possible that this branch of the arch in Indiana may be older than the Cincinnati arch proper.

Cincinnati arch.—The Cincinnati arch extends nearly across the United States, in a general southerly direction from Ontario, Canada, to northern Alabama. It had its principal development in Kentucky and Tennessee, culminating in two large features known as the Jessamine and Nashville domes. Deformation began as early as the Lowville stage of Middle Ordovician time, but the north part of the arch was developed largely during the Cincinnatian epoch. From this time on the arch remained near sea-level at most places, being submerged part of the time, and above water part of the time. It has been pointed out by P. B. Stockdale[1] that the Mississippian sediments are thick in the vicinity of the arch in Indiana. This suggests that the principal deformation was post-Mississippian in this area. However, it originated much earlier.

The arch was an important factor in partly isolating the Michigan basin during several periods subsequent to its origin. The bifurcation of the Cincinnati arch is one of its most interesting features and, as previously pointed out, it is believed that the west prong was possibly controlled by an older line of folding which is related to the Wisconsin and Kankakee folds. Another interesting feature, which is related to the Michigan basin, is the low saddle between the basin and the Appalachian geosyncline, occurring in the vicinity of Lake St. Clair. It may be found that this gap has an important bearing in tracing faunal history.

[1]Personal communication.

La Salle anticline.—The La Salle anticline[1] is a southward continuation of the Wisconsin arch, plunging steeply into the center of the Eastern Interior coal basin. It is an asymmetrical anticline with the steep side developed on the west and is suggestive of faulting. In many respects it is similar to the large Howell structure in Michigan.

There is evidence of general deformation in Lower and Middle Ordovician times, but the principal movement along the La Salle anticline occurred during late Paleozoic, throughout Mississippian and Pennsylvanian times. The forces responsible for the subsidence of the Chester and Pennsylvanian basins may have also caused the La Salle anticline. However, it has been pointed out by Cady[2] that the La Salle anticline is strongly suggestive of an initial line of weakness which localized the response to thrust. This may have been due to a fault in the deeply buried rocks or to an initial slope of deposition.

MICHIGAN BASIN

The Michigan basin is a broad structural and sedimentary basin probably originating in pre-Cambrian time. It has a rectangular form with the axis elongated northwest and southeast near the middle of the southern peninsula. It is 450 miles wide east and west and approximately the same width north and south. From the bottom of the basin westward to the axis of the Wisconsin arch the rocks rise approximately 8,500 feet, and on the south there is a rise of 6,000 feet to the west prong of the Cincinnati arch, and on the east 5,000 feet to the east prong of the Cincinnati arch. The shallowest rim of the basin is on the southeast, where there is a saddle which connects it with the Appalachian geosyncline. In this direction the rocks rise only 3,800 feet before they begin dipping eastward.

The areal geology of the southern peninsula shows the rocks to be Paleozoic in age, with some indurated Pleistocene deposits. In general, all the formations thicken basinward, thus showing evidence of the existence of the basin throughout Paleozoic deposition. The pre-Cambrian sediments have not been penetrated to any depth in the basin, but they are probably very thick, as the basin was undoubtedly a dumping ground for the erosion of the pre-Cambrian mountains. This same condition prevailed to a great extent during the Paleozoic, with the source of sediments changing in accordance with the major tectonic movements

[1]F. T. Thwaites, "Stratigraphy and General Structure of Northern Illinois," *Illinois Geol. Survey Rept. 13* (1927).

[2]G. H. Cady, "The La Salle Anticline," *Illinois Geol. Survey Bull. 36* (1920).

around the basin. We can think of the Michigan basin as a zone of comparative quiescence relative to the diastrophic movements that occurred around its rim. It is known, from the thick evaporite series which were formed, that the basin was completely isolated during several periods of deposition, because of these movements.

Folding.—The folds in the Paleozoic rocks within the Michigan basin have in general a persistent northwest-southeast trend. This trend and the parallelism of folds are more evident in the central and eastern part of the state than elsewhere. Five or six major folds with definite northwest-southeast parallel trends have been defined and some have been mapped by subsurface control for a distance of 40-60 miles. The reversal of these folds ordinarily ranges from 200 to 300 feet. However, the Howell structure has a total reversal of nearly 1,000 feet.

The folds in the southwestern part of the state have no direct similarity to those in the central and eastern part. They are much shorter and ordinarily trend in a northeasterly direction. They seem to be related to the Kankakee arch, which caused a rapid thinning of beds toward its axis.

Other structures in the northern part of the state, of minor size and seemingly without symmetry, may have been formed by compaction of beds around coral and *Stromatopora* reefs in the Traverse limestone.

There is also some indication of a somewhat pronounced northeast-southwest trend of folding in the central part of the basin which is nearly at right angles to the major system. This cross folding has not been mapped, but it may be the cause of the domes occurring along the principal uplifts.

The growth of coral structure may also be related to the folds, giving them their peculiar asymmetrical form, and may be partly responsible in the development of porosity in the limestone oil producing horizons. This is suggested by the irregularities in the thickness of the Dundee limestone, which is thicker on the Mount Pleasant fold than on its flanks. Also the fact that porosity is better developed near the axes of some of the folds than on their flanks.

Origin of folds.—Much speculation has arisen as to the cause of trends and the origin of forces sufficient to form comparatively large parallel structures within the basin. It was once thought that the dominant trend of folds was toward the center of the basin, and that they were formed as a result of settling. However, it is now known that some other theory has to be postulated to explain them.

The origin of folds within the Michigan basin is believed to be closely related to the early history of the basin itself. The basin has been an area of subsidence since early Paleozoic and probably pre-Cambrian times. A system of pre-Cambrian mountains probably extended from central Wisconsin southeastward into northwestern Indiana, marked approximately by the present axes of the Kankakee and Wisconsin arches. This period of deformation is the oldest with which the basin is related and it perhaps had its origin in the form of a long, broad geosyncline paralleling these old mountains. The oblong trend of the basin is more evident on the older formations, though the younger series reveal a more circular form.

Undoubtedly large folds and faults were present in the extremely folded metamorphosed rocks which underlie the basin, and such structures formed at the time of the geosyncline would closely parallel its axis. During the intermittent subsidence of the basin, it is logical to assume that deformation, which would slightly deflect the accumulating sediments, was more active along these old lines of structural weakness. But in order to produce such structures as occur in central Michigan, it was necessary to have an accompanying or subsequent horizontal stress which acted on these initial flexures. This stress was a resultant of regional diastrophism and was probably active during several periods, but it seems to have been most intense at the end of middle Mississippian time and perhaps later.

Thus, it seems that the folds now known in the central part of the basin are the result of vertical forces primarily active during the early subsidence of the basin, together with horizontal compression which has been effective during successive periods of its depositional and structural history. In other words, it is believed that the principal folds now existing in the later sediments are controlled by trends of folding or lines of structural weakness which existed in the old basement rocks.

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GEOLOGY OF MUSKEGON OIL FIELD, MUSKEGON, MICHIGAN[1]

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ABSTRACT

The Muskegon oil field was discovered in December, 1927, and reached its peak of production in August, 1929. This was the first field of significant commercial size in Michigan, containing 2,800 producing acres. The structure shows between 60 and 70 feet of closure on the productive porous limestone horizons, which include the Traverse, Dundee (?), and Upper Monroe, of Devonian age. The disappearance of the Devonian structure beneath the Salina salt beds seems to be explainable by the rate of eastward divergence of the Monroe-Salina section into the center of the basin.

INTRODUCTION

The Muskegon structure is in the west-central part of Muskegon County, which is in the tier of counties bordering Lake Michigan. The fold where the dome occurs is on the north side of Muskegon Lake, a large lake harbor 4 miles long east and west. The area of the producing structure extends around the northeast corner of the lake in an arcuate fashion and has a length of approximately 6 miles. The entire dome is confined to Muskegon and Laketon townships, and a part of the field is within the city limits of North Muskegon.

The city of Muskegon is accessible to Chicago by rail, water, and excellent paved roads. Direct connections may also be made with Grand Rapids and Detroit by the Pennsylvania and Grand Trunk Western lines. Three different paved highway routes lead to Grand Rapids, which is 40 miles away. According to the 1920 census, Muskegon had a population of 36,570, but "Greater" Muskegon, including suburban cities, has more than 50,000 inhabitants. Cultural facilities are entirely adequate to fulfill the needs of a growing industry. The city is the county seat and the location of several important manufacturing plants, including the Continental Motors Corporation and the Brunswick-Balke-Collender Manufacturing Company.

[1]Manuscript received, July 20, 1931. Published with permission of the State geologist.

[2]Petroleum geologist, Michigan Geological Survey.

PHYSIOGRAPHY

The area of the Muskegon structure is included in the Muskegon, Twin Lake, and Montague topographic quadrangle sheets, which were surveyed in 1929, soon after the oil field was discovered. The mapping was based on airplane-control photographs, which are now filed with the Michigan Geological Survey, Lansing. These photographs show many of the features of the oil field and the map base used for subsurface structural contour maps has been corrected in conformity with the aerial pictures.

The topography shows 70 feet of relief, with elevations ranging from 586 to more than 650 feet. The immediate region of the oil field is relatively flat, the variation in relief being caused entirely by a terrace, whose elevation ranges from 40 to 50 feet above the level of Muskegon Lake and the valley flat formed by the flood plains of Muskegon River and Cedar Creek.

The surface expression of the region is almost entirely composed of sandy lake beds which form poor soils, and the land is only infrequently farmed. The valley flat is mucky and celery raising is carried on locally. The only hills of the region are the cuspate dunes which form an almost continuous sandy ridge that fringes the Lake Michigan shore.

The land is not heavily timbered, although a few small coniferous second-growth trees can be found. The typical growth consists of oak "grubs" which are in some places very thick. The side roads are generally sandy, but the main roads are in good repair and will enable heavy trucks to operate with comparative ease.

HISTORY

At one time Muskegon was the leading lumber center on the west side of Michigan. Early drilling operations in the state were largely fostered by the lumber industry, because the waste material from the saw mills afforded ready fuel for the evaporation of brines and the consequent manufacture of salt. Rominger[1] records in 1876 that several deep borings had been made in Muskegon and mentions that the Whitney well was 1,230 feet deep. Lane[2] states that this same boring was the oldest in the community and that it possibly reached 1,600 feet. Rominger[3] comments that another hole at Muskegon penetrated to 2,627

[1]Carl Rominger, "Geology of the Lower Peninsula," *Geol. Survey of Michigan*, Vol. 3, Pt. 1 (1876), p. 84.

[2]A. C. Lane, "Deep Wells and Prospects for Oil and Gas," *Geol. Survey of Michigan Ann. Rept. for 1901* (1902), p. 232.

[3]*Op. cit.*, p. 84.

feet, the deepest well in the state at that time. The drill never reached sufficient depth in these first operations to strike rock salt; therefore, the attempt was fruitless.

Several of the first wells drilled in the neighborhood, including the Mason well drilled during 1872-1875, were described by Lane, who mentioned the discovery of small quantities of oil in the region. At that time Lane[1] recognized the flattening of the dip indicated by the Ryerson well at the east end of Muskegon Lake. In 1903, Lane[2] again mentioned the structural irregularities in the vicinity of Muskegon and suggested the possibilities of oil and gas in the Dundee horizon in an anticline which might exist across the lake. In these recommendations, he was fundamentally correct, but the sections mentioned (Sec. 15 and 16, Laketon Township) later were proved unproductive.

The discovery well in the field (Chas. Reeths No. 1, NW. ¼, NW. ¼, Sec. 9, T. 10 N., R. 16 W.) was located by Hugh D. Crider, then resident geologist for the Dixie Oil Company, Inc. This well came in on December 8, 1927, at 1,640 feet, in the upper part of the Traverse formation, making 494,000 cubic feet of gas per day. On December 21, deepening was continued and an initial production of 300 barrels of oil per day resulted. The ensuing early developments in the field occurred rapidly,[3] and later in 1928 a more prolific oil horizon was discovered in the Dixie Oil Company's A. and O. Becker No. 1, SE. ¼, SW. ¼, Sec. 4, T. 10 N., R. 16 W., from porous beds considered by many to be of Dundee age. The large producing oil and gas wells obtained from this formation brought many operators to the scene of development, and by August, 1929, the field had reached its peak of production of 18,570 barrels daily. In January, 1931, the Muskegon district was producing 2,020 barrels per day. During the development of the area the maximum production from one well was approximately 3,000 barrels daily and the largest initial gas flow was in excess of 25,000,000 cubic feet.

STRATIGRAPHY

The detailed stratigraphy of the Muskegon field as determined from the records of deep wells includes beds ranging from the Lower Mar-

[1]A. C. Lane, *op. cit.*, pp. 232-34; "The Geology of Lower Michigan with Reference to Deep Borings," *Geol. Survey of Michigan*, Vol. 5, Pt. 2 (1895), pp. 20, 71, Pl. 43.

[2]*Idem*, "Deep Borings for Oil and Gas," *Geol. Survey of Michigan Ann. Rept. for 1903* (1905), pp. 275, 276.

[3]R. B. Newcombe, "Oil and Gas Development in Michigan," *Michigan Geol. Survey Pub. 37*, Pt. 3, Geol. Ser. 31 (1928), pp. 244-55.

shall formation of Mississippian age to the St. Peter sandstone of Ordovician age, which was encountered at a depth of 4,710 feet. The best known vertical section in the area of the entire producing structure extends from the surface to a depth of 2,050 feet. This section has been previously described[1] as follows.

The record of the discovery well drilled by the Dixie Oil Company on the A. and O. Becker farm (Fig. 1) may serve as a type section for the Muskegon area. Generalized data furnished by other wells in the field are included in this figure in order to show variations in thickness and conditions peculiar only to certain wells. The bedrock is covered by 190 to more than 300 feet of glacial drift, which consists largely of lake clay and dune sand. The first beds encountered are the fine-grained gray and pink sandstones of the Lower Marshall formation. This formation is everywhere water-bearing and the water is usually brackish.

The Lower Marshall sandstone is underlain by the blue-gray shales and calcareous shales of the Coldwater formation. One calcareous phase of the Coldwater is a gritty granular limestone, which is persistent throughout the field at a depth of about 270 feet below the top of the formation. At many places it contains oil and gas and here and there some water. In the lower part of the Coldwater there is a bed of red, shaly fossiliferous limestone, which can be so easily recognized that it is the most useful horizon marker in the field. It has not yet yielded determinable fossils. Oil and gas are found in considerable quantities at this horizon in some parts of the producing area.

The Berea can not be definitely identified at Muskegon. The vari-colored greenish gray and gray beds of sandy shale found about 30 feet below the red limestone probably represent beds nearly equivalent to the Berea-Bedford (*Ellsworth shale*) of eastern Michigan. In their porous parts in the Muskegon field they contain small quantities of oil. Near the bottom of the group these beds become less sandy and their color changes to a darker gray.

The Antrim shale, which overlies the Traverse, is usually considered Upper Devonian, but the exactness of this correlation is still in controversy. The formation consists of brown and black pyritous shale containing abundant *Sporangites huronensis*. A concretionary zone near the bottom of the Antrim shale generally logged by drillers as limestone is probably nearly equivalent to a like zone observed at Kettle Point, in Ontario; at Paxton, in Alpena county; and at Norwood, in Charlevoix county, Michigan.

The Traverse group at Muskegon includes an average of about 430 feet of strata. Of this thickness, 60 to 70 feet should be classified as Upper Traverse (Thunder Bay), 200 to 210 feet as Alpena-Petoskey limestone, 160 feet as lower Traverse (Long Lake), and from 5 to 10 feet as Bell shale. The Bell shale is at many places split into two beds by a layer of limestone from 3 to 12 feet thick. At the top of the Lower Traverse there is a 30-foot bed of anhydrite and dolomite. This bed was probably formed at the end of Long Lake time, when the sea was shallow and the land was a desert in which there was considerable evaporation and consequent concentration of sulphate. The re-

[1] R. B. Newcombe, "Middle Devonian Unconformity in Michigan," *Bull. Geol. Soc. Amer.*, Vol. 41 (1930), pp. 732-33.

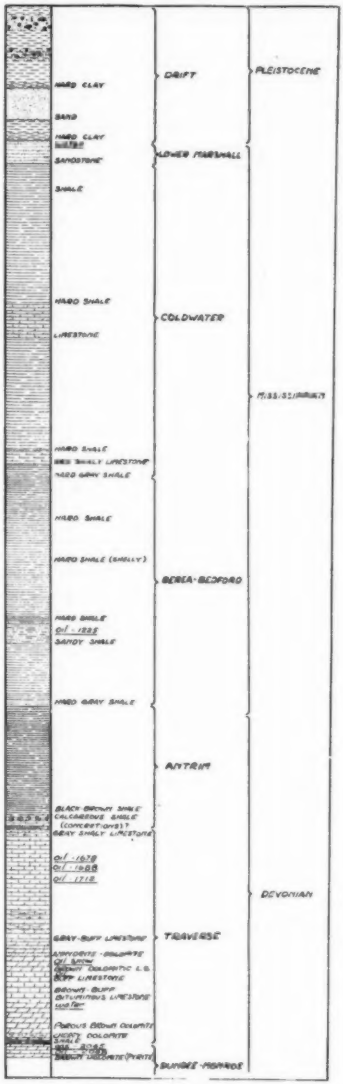

FIG. 1.—Typical well record in Muskegon oil field. (Dixie Oil Company's A. and O. Becker well No. 1, Sec. 4, T. 10 N., R. 16 W., Muskegon Township, Muskegon County. Elevation: 631.8 feet.)

working of the Monroe-Salina deposits may also have contributed to this concentration.

The oil-bearing beds include one (20 to 30 feet thick) in the Alpena-Petoskey limestone; one at the top of the Lower Traverse, below the bed of anhydrite; and one (ranging in thickness from a few inches to several feet) below the base of the Bell shale. The water-bearing beds are associated with the oil-bearing beds and are also about 100 feet below the top of the Lower Traverse.

The base of the so-called Dundee has not been distinguished clearly enough to show accurately the thickness of that formation, which is probably variable but may at some places reach 20 or even 30 feet. It was once supposed that the water found about 100 feet below the top of the Lower Traverse (Fig. 1) represented the base of the Dundee and that the Bell was absent, but studies covering a wide area, a close observation of the pay horizon, and the discovery of some fossils in the Bell shale furnish evidence that is strongly adverse to this supposition. It is possible, however, that the lowest fossiliferous productive bed beneath the Bell shale may be the Anderson limestone, of Detroit River age.

The deeper rocks in the Muskegon district are known from the well drilled by the Muskegon Deep Well Syndicate in 1930. This boring encountered gas in a horizon of the Detroit River dolomite at approximately 200 feet from the top of the formation. The top of the Salina salt was penetrated at 2,885 feet, the top of the Niagaran series at 3,600 feet, the Trenton limestone at 4,315 feet, and the hole was abandoned at a total depth of 4,754 feet. A showing of oil occurred in the Salina dolomite beds at 3,370 feet, and in the Manistique formation at 3,601 feet, brine in the Trenton limestone at 4,575 feet and in the St. Peter sandstone at 4,735 feet.

STRUCTURE

General features.—Muskegon County is on the west side of the Michigan synclinal basin, where the general regional dip is northeastward. The approximate strike of the beds is N. 40° W., although in the northwest corner of the county the strike veers almost to north. The district is evidently in a broad regional syncline which is marginal to the larger basin including the entire southern peninsula of Michigan. This regional syncline causes the dip of the rocks to change from northeast in the southern part of the county to east in the northern part. The Muskegon anticline seems to be a product of the structural factors which control the change in the directional components of the regional dip.

As rocks are not exposed in Muskegon County, the entire knowledge of conditions of structure is based on subsurface data obtained from drilling. Two contour maps have been prepared to show the size and

TABLE I

LOG OF MUSKEGON OIL CORPORATION'S (MUSKEGON DEEP WELL SYNDICATE'S) H. HEINZ NO. 5

Location: NE. ¼, NE. ¼, Sec. 8, T. 10 N., R. 16 W., Muskegon County. Elevation: 636 feet above sea-level. Log condensed from record compiled by O. F. Poindexter and R. B. Newcombe from driller's log and samples. Casing: 245 feet of 12½; 335 feet of 10; 2,231 feet of 8¼; 4,675 feet of 6⅝-inch.

Formation	*Depth in Feet*
Pleistocene. Sand	245
Mississippian	
Lower Marshall and Coldwater formations. Blue shale and limestone. Red limestone at base is key bed in Figure 2	871
Ellsworth formation. Blue shale, limy sandstone	1,380
Devonian	
Antrim formation. Brown shale	1,600
Traverse and Dundee formations. Shale, limestone	2,038
Detroit River (Upper Monroe) formation. Dolomite, brown, buff, and gray, with a little anhydrite, 2,038-2,355. Gas showing, 2,244-2,265. Anhydrite and dolomite, 2,255-2,575	2,575
Silurian	
Bass Island (Lower Monroe) formation. Dolomite, gray and brown, argillaceous, with a little pink gypsum and anhydrite	2,885
Salina formation. Salt, 2,885-2,930; 3,080-3,340; 3,390-3,590. Oil showing, 3,370-3,375. Remainder, limestone, gray, buff, brown, argillaceous	3,600
Niagaran series	
Manistique formation. Limestone, buff, gray, brown. Oil showing, 3,601	3,615
Burnt Bluff formation. Limestone, buff, gray, red, brown. Red oölites? 3,615-3,650	3,805
Mayville formation. Limestone, dolomitic, buff and brown	3,820
Cataract formation. Cabot Head shale member: shale, dark red and gray, ferruginous, 3,820-3,845. Manitoulin member: shale and dolomite, gray and brown	3,975
Ordovician	
Cincinnatian series	
Richmond in part. Dolomite and shale, brown and gray	4,230
Utica formation. Shale, darker gray	4,315
Trenton formation. Dolomite, 4,315-4,320. Limestone, brown, buff, gray. (Water, 4,575-2,500 in hole)	4,710
St. Peter formation. Sandstone, white. (Hole full of water)	4,735
Total depth	4,754

outlines of the dome in the vicinity of the city of Muskegon. The first of these maps (Fig. 2) has been drawn by using as a key bed the persistent fossiliferous shaly red limestone in the lower part of the Coldwater strata. This bed is present regularly throughout the field, and, though in few places more than 20 feet thick, it can be recognized easily in all parts of the district. The deductions regarding structure which led to

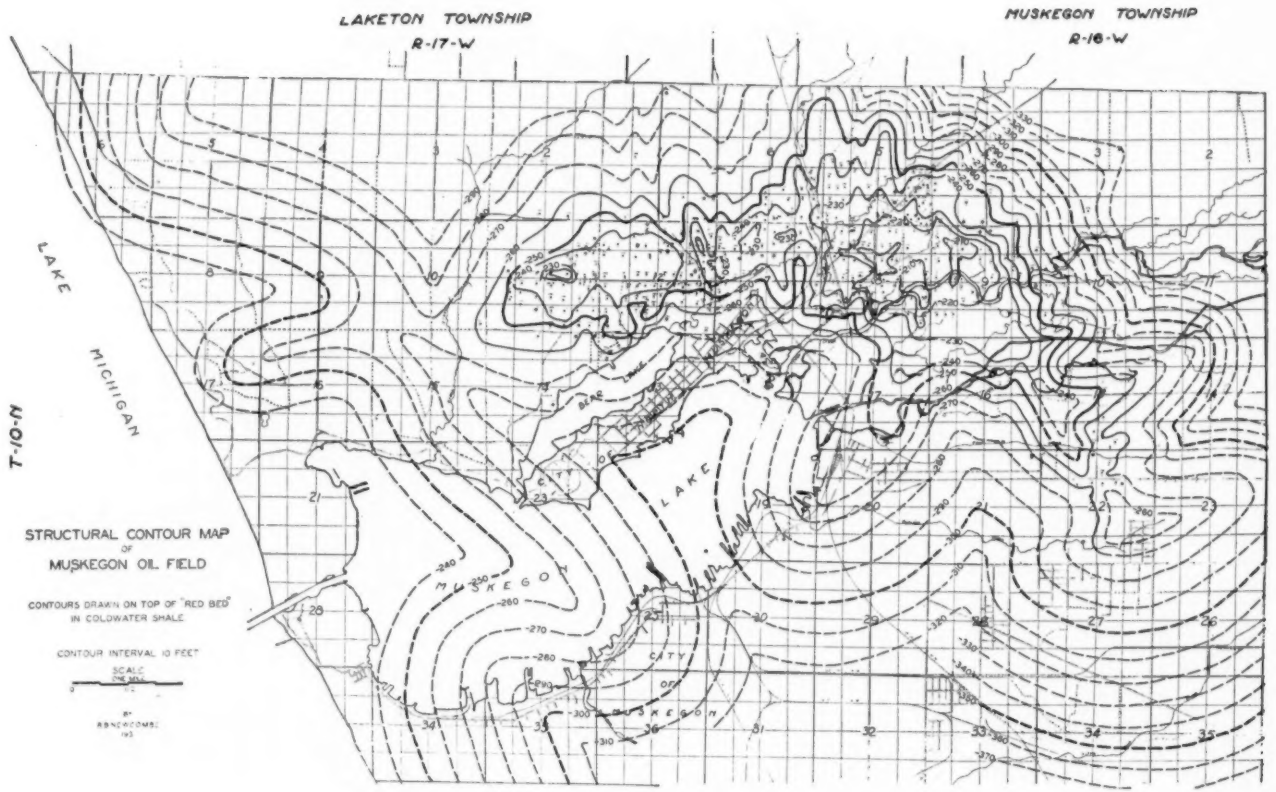

FIG. 2.—Structural contour map of Muskegon field drawn on top of red bed in Coldwater shale.

the discovery of the field resulted from comparisons between wells made with this horizon as a basis.

Coldwater structure.—The anticline is elongated east and west, although the outline of the axis is an arc which bends southeast. There are several small domes on the fold and the total amount of closure is between 60 and 70 feet. The lowest closing contour on the red bed is 270 feet below sea-level and the highest structural elevation is −203 feet. The steep flank of the structure is on the northeast side and the maximum dip is not much more than 100 feet per mile. The dip of the other limb is approximately 50 feet per mile.

The highest part of the Muskegon anticline is in Sections 8 and 9, Muskegon Township, at the approximate intersection of two axes of folding. The arch with the northwest-southeast axis shows the sharpest dip, and is probably the controlling feature. The east-west axis is narrow and this cross fold probably trapped the largest quantity of oil, as shown by the wells, which were more productive on the west side of the structure than on the east side. The largest Dundee gas wells were confined to the highest parts of the structure, although local porosity determined some of the largest Traverse wells in the field.

The numerous sharp reëntrants shown by the structural contours indicate that secondary movement occurred along the crest of the fold. The regularity with which these reëntrants occur suggests a relation to jointing or faulting. When first recognized they were considered to be the product of erosion at a surface of disconformity. The persistence with which these features continued through the deeper beds has prompted a different conclusion as to their origin. The reëntrants are now thought to have been caused along the directions of prominent joints, by slump faults which were formed as a result of solution in the Salina rocks beneath. Structure of this type has been observed in many places in New York.

"Dundee" structure.—The structure in the Devonian rocks conforms closely in general plan with the Mississippian beds above. The Muskegon anticline, contoured on the base of the Bell shale or the top of the so-called "Dundee" formation, is shown in Figure 3. The many points of similarity between this map and the previous one on the "Red bed" are strikingly evident. The sharp reëntrants do not correspond exactly, but their directional orientation is very similar. The highest parts of the structure are nearly the same as before, and the degree of dip is very nearly the same on the northeast limb of the fold. The dips on the south side of the anticline are somewhat steeper than shown by the contours

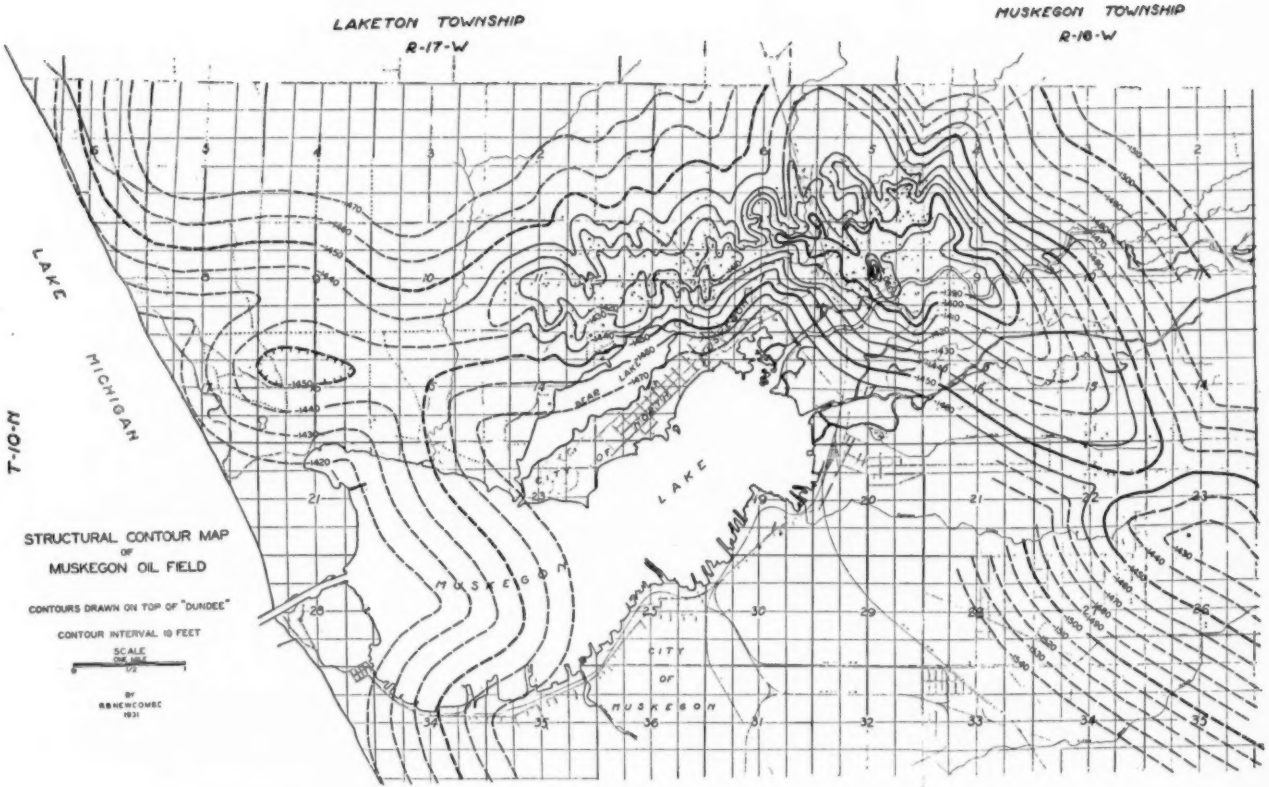

FIG. 3.—Structural contour map of Muskegon field drawn on top of "Dundee" formation. Contour interval, 10 feet.

drawn on the top of the Coldwater red horizon. This general seeming sharpening of folding in the deeper beds is probably explainable by the re-occurrence of deformation along the same axis, and possibly some compaction and depositional settling consequent to sedimentation. The amount of structural closure in the "Dundee" beds does not greatly exceed 60 feet, which is even less than the indicated closure in the lower Coldwater "Red bed." This condition suggests that the steepening of the fold in the deeper rocks is only local and there is actually very little difference between the effects of deformation on the Mississippian and the Devonian strata.

Niagaran structure.—There is a pronounced change in the amount and localization of folding beneath the Salina beds. The exact nature of this change is not known because only two wells have been drilled deep enough to go through the Salina section. One of these wells (K. Savacool No. 1, SW. ¼, SW. ¼, Sec. 2, T. 10 N., R. 17 W., Laketon Township) is low on the "Dundee" structure and the other (H. Heinz No. 5, NE. ¼, NE. ¼, Sec. 8, T. 10 N., R. 16 W., Muskegon township) previously described, is structurally high, as shown by comparing the "Dundee" elevations. In spite of the fact that the Heinz well is 60 feet higher than the Savacool well on the mapped anticline (Fig. 3), the Niagaran beds are 60 feet lower, making a total difference of 120 feet in structural elevation. This anomalous condition deserves careful consideration, for the correct explanation has a vital bearing on the future problems of the persistence of folding at greater depths beneath the Devonian rocks in Michigan.

The existence of thick salt beds and several important stratigraphic "breaks" between the Dundee and Niagaran rocks probably explains the structural discrepancy. The exact explanation of how these factors caused the change in structure is more difficult to give, but several hypotheses might possibly account for the relation. These theories include the following.

1. The mechanical adjustment of structure with depth because of the divergence of the Monroe-Salina section, including the salt beds, into the center of the basin. This tilted condition might cause a shallow fold to be represented in the lower beds by a terrace or plunging nose, with insufficient closure to trap any oil and gas. It might also influence the structure so as to shift the anticline one way or another.

2. The occurrence of a topographic hill in some of the beds above the Salina resulting from the solution of the Salina beds themselves, this hill causing a depositional structure due to differential settling over

its irregularities. A theory of this type would account for the absence of folding at depth and the thinning of the salt beds off the flanks of the structure.

3. The existence of a fault beneath one of the formational "breaks" between the Dundee limestone and the Niagaran series. The resulting escarpment would probably be on the downthrown side of the fault and the topographic ridge would be structurally low rather than high. Deposition over this ridge might cause a fold which would be synclinal on the upthrown side of the fault.

4. The solution of salt along planes of faulting and fracturing at some time after salt deposition, but before the superincumbent load was very great and the beds were sufficiently competent to hold cavities. This process might result in a slight arching which would increase in intensity by the additional amount of solution.

5. Flowage of incompetent salt beds as the result of the folding of competent beds above, thus accounting for the thickening of the salt series "on structure" and the dissipation of folding at depth. If the salt beds accommodated the warping by active flowing rather than bending, the structural disturbance occurring beneath the salt would be different from that occurring above it.

Lane[1] has also suggested the possibility that, in the warping of the strata, they acted like a bent beam in which the upper beds were slightly folded due to compression while the lower beds were in tension; thus, less affected.

A critical examination of these theories seems to favor the acceptance of the first hypothesis outlined. Theories 2 and 3 give conditions which necessitate the shallow fold being of the compaction type, in which folding increases in intensity at depth. The two structure maps (Figs. 2 and 3), showing approximately the same amount of closure in the Mississippian and Devonian rocks, suggest that the deformation is not due strictly to compaction. This evidence tends to refute theories 2 and 3. The conditions of theory 4 would result in secondary faulting, for which some proof exists, but the limiting qualifications of the hypothesis are so exacting that the theory seems illogical. The relationships required by theory 5 probably exist to a certain extent. The "salt plugs" of southeastern Utah and southwestern Colorado show some of the conditions[2] resulting from the sharp arching of strata containing

[1] A. C. Lane, personal communication.

[2] Thomas S. Harrison, "Colorado-Utah Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 2 (February, 1927), pp. 111-33.

H. W. C. Prommel and H. E. Crum, "Salt Domes of Permian and Pennsylvanian Age in Southeastern Utah and their Influence on Oil Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 4 (April, 1927), pp. 373-93.

salt beds. Nevin[1] states that salt layers observed in the mines near Ithaca, New York, show ample evidence for the flowage of salt, and the formation acts as a very plastic, incompetent bed. Gliding planes parallel with the faces of the dodecahedron are present in the rock salt obtained from Michigan at the Oakwood mine of the Detroit Rock Salt Company. These facts seem to be sufficient evidence to substantiate the theory that some flowage has probably occurred. The existence of thick competent beds beneath the salt and the gentleness of the folding seem to discount the significance of the explanation offered in theory 5.

The thickening of the salt beds and approximate rate of divergence of the Silurian-Devonian rocks from Muskegon into the central part of the basin area is very great. The mathematical computation of the divergence rate of these beds between the two Muskegon County wells gives a figure which practically accounts for the loss of structure in the deeper beds. The logical conclusion is that the general change in attitude of the lower strata caused by disconformity and overlap explains the absence of similar characteristics of folding in the deeper rocks that exist in the shallower formations.

Muskegon County is close to the border of the salt-bearing rocks and this locality in post-Salina time must have been an area of intense solution and consequent slumpage of the beds. This relationship may possibly in some manner explain the change in the strike of the rocks which occurs across the county. The exact causes for the east-west downwarp extending across the northern part of Muskegon County can only be postulated, but some possible connection between the regional structure and the border of the Salina salt is strongly suggested.

Comparison with other Michigan folds.—The generalized features of the Muskegon anticline are similar to those of the other domes found in the state. The major axis, almost parallel with the regional strike, the steep dip on the basinward side of the arch, and the wide comparatively flat-bottomed syncline are typical Michigan folding. The sharp northeast dip is of nearly the same degree exhibited on the southwest flank of the Saginaw structure in eastern Michigan. A strong narrow east-west cross fold on the gentler dip side of the dome has also been found on the principal producing structure near Mount Pleasant, central Michigan. The northwest-southeast axis of the structure is parallel with the trend of other folds in the state and suggests that this direction is the more important of the two lines of folding which contributed to the formation of the dome. The occurrence of large quantities of gas is

[1]C. M. Nevin, written communication (1931).

typical of anticlines on the periphery of a major basin, and the proximity to the Wisconsin region may have exercised some influence on the degree of metamorphism which probably contributed to the extensive amount of gas.

OIL AND GAS DEVELOPMENT

The Muskegon field is now in the waning stages of development, and drilling operations largely include deepening of old wells to the newly discovered gas horizon in the Detroit River (Upper Monroe) formation. The productive horizons, in the order of their most important output, are the "Dundee," Upper Traverse, Lower Traverse, and Upper Monroe porous members. These "pay" zones are entirely limestones or dolomites and the principal porosity probably has been formed by solution below surfaces of disconformity.

At the close of January, 1931, the area had produced 4,826,201 barrels of oil, and probably in excess of 5,000,000,000 cubic feet of natural gas. On the first of January, 1931, 629 wells had been commenced in the field and 439 wells completed. Of this number, 304 were "Dundee" oil wells; 48 were "Dundee" gas wells; 57 were Upper Traverse oil wells; 14 were Lower Traverse gas wells; 14 were Lower Traverse oil wells; 2 were Monroe gas wells; and 64 were dry holes. The remaining wells were either being drilled or were abandoned.

The crude oil from the Traverse has an average gravity of approximately 37° Bé., and is a high-grade paraffine-base, sweet oil (sulphur 0.336 per cent). The gasoline content ranges from 34 to 35 per cent; the kerosene content is 14 per cent; and the remainder is crackable residuum. The "Dundee" crude ranges from 37° to more than 39° Bé. gravity, but it is a sour oil (sulphur, 0.98). The gasoline content varies from 26 to 29 per cent; the kerosene, from 23 to 24 per cent; the gas oil is 10 per cent; the lubricating distillates, 16 per cent; and the residuum, approximately 23 per cent. The current prices paid for the Muskegon crude oils have been the same as the Mid-Continent gravity scale.

The limits of productivity in the field may be determined from Figure 4, which shows graphically the areas where oil and gas were obtained from the different horizons. It is evident from this map that the continuity of "Dundee" porosity was much greater than that of the other "pay" zones. The Upper Traverse areas seem to be particularly segregated into small patches which strongly suggest that local factors determined the porous parts of the formation.

The field was extensively over-drilled because town-lot subdivision permitted abnormally close spacing of wells. The acre yield is compar-

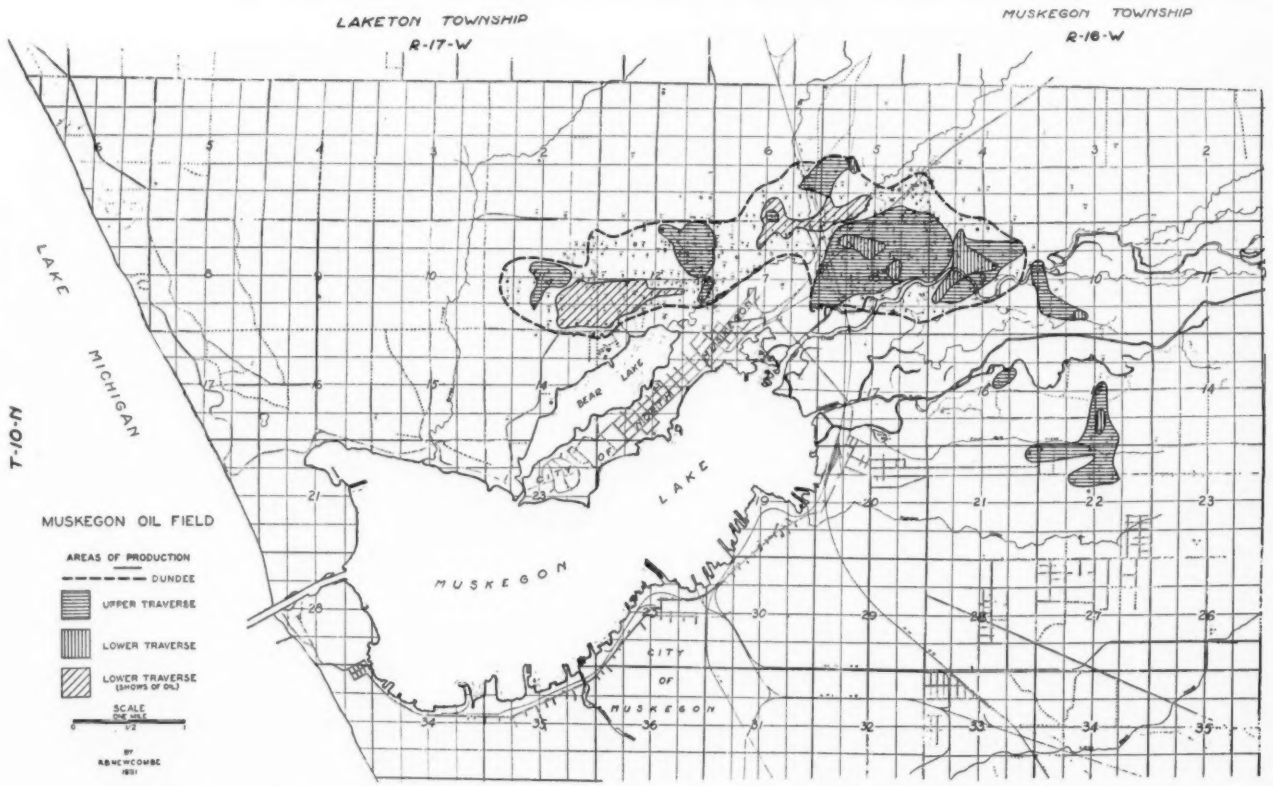

FIG. 4.—Map of Muskegon field showing approximate limits of areas of production from different producing horizons.

atively small, because of the rapidly accelerated edge-water encroachment. The present yield for the field has been calculated[1] to be 1,726 barrels per acre.

[1]F. R. Frye, personal communication.

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VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 169-177, 4 FIGS.

ASYMMETRIC FOLDS WITH REFERENCE TO GERMAN SALT BODIES[1]

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ABSTRACT

A brief discussion is presented of the conditions of asymmetry and overhang in the salt domes of Germany. Reference is made to the folded region of central Spain, and the orogeny here is likened to that in Germany. This paper is offered to facilitate the comparison between German and American salt-dome phenomena.

In the meetings and publications of The American Association of Petroleum Geologists, American geologists like Donald C. Barton[3] have presented numerous papers on German salt domes and have given excellent information on this branch of German geology.

In the present stage of the study of the American salt domes, a subject worthy of especial attention is the asymmetry of the German salt domes. Asymmetric salt bodies in Texas and Louisiana were objects of discussion at the meeting of the Association in San Antonio. Such asymmetric salt bodies in Germany seem to exemplify a special type of structural asymmetries in the so-called Saxonian type of mountain building.[4]

In Germany the phenomenon of lateral overhang of salt bodies has been known for some time, because many borings which struck the Permian salt encountered younger formations below. Such a condition was found in an important salt zone in southern Hanover, the Leine Valley anticline. Barton has referred to this area.[5] The subsurface structure has been checked by several borings and salt mines, and the borings have encountered the Lower Triassic (Buntsandstein) below the salt.

[1]Read before the Association at the San Antonio meeting, March 19, 1931. Manuscript received, July 1, 1931.

[2]Geological Institute.

[3]Donald C. Barton, "The American Salt-Dome Problems in the Light of the Roumanian and German Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 9 (December, 1925), p. 1227.

[4]Hans Stille, "The Upthrust of the Salt Masses of Germany," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), p. 417.

[5]Donald C. Barton, *op. cit.*, p. 1253.

From this it was believed that the salt was not Permian in age, but Lower Triassic (Röt), which is known to contain salt elsewhere in Germany. It was further concluded that there were potash deposits not only in the Permian, but also in the Lower Triassic, because the salt in the Leine axis is associated with potash salts. But as underground development proceeded, the true nature of the structure was revealed. The red sandstones below the salt were proved to be, not older, but younger than the salt, tectonic processes having brought the salt into a position above the sandstone.

This illustrates a considerable overhang of a salt body, and a regional study shows that the salt hangs over toward the east in the northern part of the anticline, and over toward the west in the southern part. This overhang in different directions is a result of the general structural relations of the Leine Valley anticline. It characterizes certain general problems of Saxonian geology. In the northern part of the anticline, the eastern wing is downfaulted, whereas in the southern part the western wing is dropped; the structure of the anticline is one-sided in so far as the higher block has been moved obliquely above the dropped block, and the salt, which belongs to the higher block, shows this overhang particularly well.

The internal structure of the salt body below the Leine Valley is accurately known; and though the overlying strata are less disturbed in the salt, closely compressed isoclinal folds in the northern part of the anticline are overturned in an easterly direction, and in the southern part both overhang and folds are overturned toward the west.

Farther north is found another structural type in which the salt occurs, namely, the salt dome or salt stock. Salt bodies of this type are no longer capped by the Lower Triassic sandstone, but occur among rocks of much younger age. These stocks may justly be compared with the salt domes of Texas and Louisiana. Here, too, are found many examples of lateral overhang of the flanks of the domes. Thus, in a salt dome known as Einigkeit, near the town of Fallersleben, the salt is bordered by late Triassic and Jurassic rocks. The surface of the salt dips east on the east side, but when a shaft was sunk on the west side it was found that the salt projects on this side into the wall rocks in the form of a broad spur. Beginning in the Upper Triassic, the shaft struck the salt; but a short distance deeper it entered other Mesozoic beds. A tunnel was then driven eastward, and after penetrating several hundred feet, it entered the salt.

Here, too, the salt is isoclinally folded, and the folds are overturned toward the west, exactly like the westward overhang.

Thus, the one-sidedness of the folding is manifested not only by the form, but also by the internal structure of the salt body. The overhanging flanks are only a part of the greater phenomenon of the asymmetry of the German salt bodies. This asymmetry of the German salt bodies is only a special type of the asymmetry of the Saxonian mountain-building.

Mountain ranges of the alpine type are especially characterized by a one-sided structural plan. It is common to see the folds, thrusts or Decken, overturned toward the "foreland." As far as the region north of the Alps is concerned, to which region Germany belongs, some examples of one-sided structure, especially thrusts, have been known for a long time, and the relative movement of one block above another may be considerable in many places. The Osning anticline, in the northern part of the Teutoburger Wald, is a good illustration of such a type, because its structure has been ascertained through borings, which showed the lateral thrust to be considerable. Because of subsequent erosion, older strata are "floating" on top of younger rocks, a phenomenon which in alpine terminology is known as "Decke" ("Nappe").

Although such major thrusts have been known for some time, they were explained, by Eduard Suess, as strictly local phenomena due to local instabilities. It was thought, for example, that if one block in the crust subsided, the adjacent block would rise obliquely over its neighbor. Suess used the phrase "overthrusts overriding the subsiding blocks." But structural asymmetries of regional importance which occur in definite zones had not been expected in the block-faulted regions of Germany.

In recent years, the geologists of the department of Göttingen have studied the Saxonian asymmetries in some detail, and in order to widen the field of their observations, have extended their studies into Spain.[1]

Central Spain, like Germany, is a part of the foreland of the alpine chains. But not all of Spain is beyond the reach of alpine folds; for the Pyrenees in the north, and the Betian chains in the south, belong to the alpine system.

Because of the arcuate form of the alpidic folds, the Iberian block is surrounded by them not only on the south side, like Germany, but also on the north side. The research was conducted in the Celt-Iberian

[1] Hans Stille, "Über Einseitigkeiten in der germanotypen Tektonik Nordspaniens und Deutschlands," *Nachr. Gesellsch. d. Wiss. Göttingen, Mathem.-phys. Kl.* (1930), p. 379.

Mountains, the region between the Ebro basin on the north and the Tajo basin and the eastern Betian ranges on the south (Fig. 1). Beginning in the north, it was found that the fundamental structural elements closely resemble those of the German Saxonian orogeny. But asymmetries are much more numerous than in Germany, and their direction is predominantly north. (In Figure 1 the arrows indicate the directions of the asymmetries.) When the work was continued in the south, different conditions were found. The same kind of "germanic" mountain-making is here connected with conspicuous asymmetries toward the Tajo basin and Betian mountain chains. Structurally, Celt-Iberia can be divided into a large northern part with asymmetries

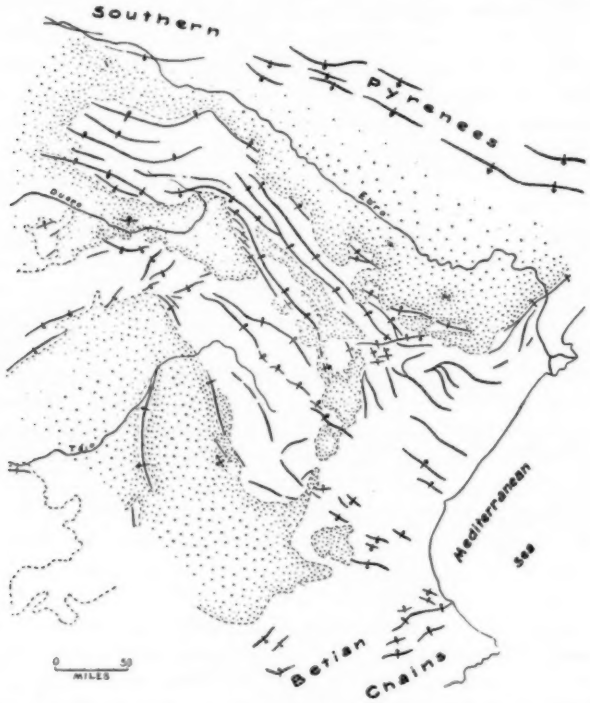

FIG. 1.—Tectonic sketch of Celt-Iberian mountain system between Ebro basin and Tajo basin (northeastern Spain). (After studies conducted by Geological Institute of Göttingen.) Arrows indicate asymmetries of folds.

toward the north, and a smaller southern part with asymmetries toward the south (Fig. 2).

However, the southern Pyrenees are overturned toward the south against their southern borderland, and the Betian chains are folded over toward the north. Thus (Fig. 2), the strong asymmetries of the moun-

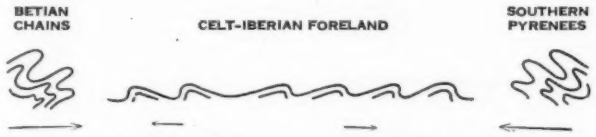

FIG. 2.—Diagram of asymmetries of folding in eastern Spain.

tain chains of alpine type toward the Celt-Iberian foreland are contrasted with more subdued asymmetries within the Celt-Iberian block toward the fringing folded mountain chains.

The occurrence and arrangement of the structural asymmetries in central Spain is a fact of *regional* importance. But as the deformation of the crustal block in other respects strongly resembles the germanic type of fault-folding, it became necessary to re-examine the problem of one-sidedness in Germany. For completeness, it became necessary to examine not only the thrusts, but every other kind of one-sidedness, as the overturned folds, and even those anticlines where one flank is steeper than the other.

Such an extended survey has recently revealed, also in Germany, one-sided structures, the writer believes, of *regional* extent.

Figure 3 illustrates two examples. Two old blocks, the Rhenish mass on the west and the Harz Mountains on the east, are represented. Both units are composed of Paleozoic strata which were folded during Carboniferous time. Both appear like islands between the Mesozoic sediments which have been deformed by the Saxonian mountain-building. Although the present outlines of these two old blocks are determined by fault zones of Saxonian age, the paleogeography of the region shows that both the Rhenish mass and the Harz block have risen as parts of geanticlines prior to the Saxonian mountain-making; the Rhenish mass emerged somewhat earlier than the Harz Mountains. For the subsequent Saxonian deformation these geanticlinal blocks have determined the general form, acting somewhat like a frame.

North of the Rhenish mass is the Lower German basin. This area subsided most after the Variscan mountain-making; therefore, the post-

FIG. 3.—Asymmetric folds in northern periphery of Rhenish mass and Harz Mountains.

Paleozoic sediments are especially thick. The folding has been not only most intense, *but also most one-sided.*

Here are found the overthrusts of the Osning anticline previously mentioned. They are turned toward the south, against the Rhenish mass. Farther south are the axes of the Egge Mountains. Unfortunately, only a small part of them is known, because within a short distance they disappear below the Cretaceous of Westphalia which overlies them unconformably. Nevertheless, in the Egge Mountains, numerous asymmetries toward the Rhenish block can be seen. Also west of the Cretaceous of Westphalia, near the German-Dutch border, many folds are asymmetric toward the south, and some borings indicate thrusts toward the south.

As with the Rhenish block, so the Harz Mountains are surrounded by a marginal belt of folds, which show overthrusts toward the south, or at least steeper flanks on the southern sides.

It is to be remembered that the older interpretation of the Saxonian overthrusts, so far as they were known at the time, was that they were caused by *local* forces, for example by the movement of higher, horst-like blocks toward the adjacent dropped blocks. But if it is realized that asymmetries with the same direction are not only common, but may predominate to the exclusion of all other structures in some zones, it is impossible to think of an accidental concentration of various local factors. On the contrary, the writer thinks it justifiable to assume a *regional* force which has been instrumental in directing the folding, comparable with the related conditions in Spain.

It has been recognized that in Spain and middle Europe, not only certain *local* asymmetries, but even *entire groups* of them are compatible with the structural behavior of what is termed a foreland. The writer is inclined to think that this point may be of some significance also for the analysis and understanding of some foldings in America.

Further, it has been learned that the asymmetries of the German salt domes are only a part of the larger asymmetries observed in the Saxonian foreland. But as the salt is very plastic, it is able to serve as a particularly sensitive indicator of asymmetric structural processes. Thus, the German salt mines afford excellent criteria for the explanation of the regional asymmetries of the Saxonian block; they may furnish valuable information even where the surrounding sediments fail to record such asymmetries.

If the larger asymmetries of Saxonian mountain-building are explained by the folding forces, the inclination will be to explain the asymmetric forms and structures of the salt bodies in the same way. This corresponds with the opinion of many German geologists, that the formation of the salt domes is on a wide scale caused by lateral compression.

However, there is also evidence of *crustal tension* in the Saxonian block. These ruptures are of the same general age as the folds. Many of them may be interpreted as *accessory phenomena* of the Saxonian folding; in fact, some of them may have been caused by the folding. F. Lotze, of Göttingen, has recently studied these features.

Figure 4, representing the region of the Teutoburger Wald,[1] illustrates one of these fault zones. The wavy line indicates the general direction of the folds. At the left is the Rhenish block, the borderland of the folds. Notice this system of grabens which radiate east-northeast. They originate where the trend of the folds changes from north to northwest. These are the much discussed "graben of Falkenhagen." They, too, are fault blocks caused by tension.

The folds in this region may be considered a result of a northeast movement of the consolidated Rhenish mass. Because of the curved outline of this block, the general movement toward the east-northeast is transformed into an easterly force in the south, and into a northeasterly force in the north. This, in turn, combined with the reaction from east and northeast, implies, according to the parallelogram of forces, a southward component (t') on the south, and a northward component (t) on the north. Thus the subsurface is disrupted.

Such zones of tension may become important for the rise of the salt. The salt may stand under lateral compression or only under the pressure of the overlying sediments. And whenever tension cracks may gape, the salt is ready to advance into them.

[1] F. Lotze, "Das Falkenhagener Störungssystem," *Abh. Preuss. Geol. Landesanst. 128*, pp. 38-128.

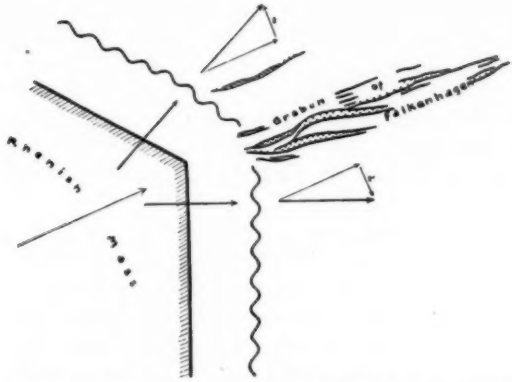

FIG. 4.—Graben of Falkenhagen (Westphalia) in tension zone. (After F. Lotze, Göttingen.) Forces of reaction from northeast are neglected.

The writer has tried to present some observations and ideas concerning the asymmetric folds in the old consolidated blocks which are the foreland of the European alpine mountain systems. He felt justified in doing so, because the conclusions may furnish a useful basis for the discussion of asymmetric structure of salt domes, and for discussing the phenomenon of overhang, which is of such great interest in America.

But, certainly, many American geologists will hardly consent to apply this manner of explanation of German salt domes and their characteristics to the salt domes of Texas and Louisiana—and the writer agrees in part. They will say that in the domain of American salt domes even those smaller foldings are lacking which are found in Germany in the form of Saxonian folding. In Germany, however, there are places where the salt is distinctly folded but where the beds overlying the salt are not folded or are only faintly folded. This may be explained by the fact that the force which produces the folding is so weak that it can set in movement the mobile salt, but not the normal sediments. The writer likes to compare this movement with that of igneous intrusions. And if, in this sense, with Hans Cloos, S. von Bubnoff and others, we refer to plutonic intrusions as an extreme type of tectonic movement, do we not have the clear case of the restriction of the tectonic movement entirely to the extremely mobile material?

Perhaps it is desirable to discuss such thoughts in connection with the American salt domes. Perhaps here, also, it may be that at very

great depths the salt, and substantially *only the salt*, was affected, folded, and upthrust.

However, this would remain only a *partial* explanation. In agreement with Barton and many American geologists, the writer is convinced that the upthrust of the salt in Texas and Louisiana is, *in considerable part*, an isostatic phenomenon.

In Germany the predominant force has been that of folding, but certainly in many places isostatic forces may have taken a part and, probably, a larger part than many German salt-dome geologists, including the writer, formerly were willing to admit. In this connection, the writer's brief stay in the American salt-dome fields and his conversations with the American salt-dome geologists have already opened his eyes somewhat. And, *vice versa*, the results gained by the study of the German salt bodies may lead to the suggestion that for the upthrust of the American domes, also, isostasy has not been the *only* motive force.

Subsequent note.—After the meeting of The American Association of Petroleum Geologists at San Antonio, Texas, while visiting the salt domes of southern Louisiana, the writer had the opportunity of discussing the upthrust of the salt masses with W. C. Spooner. According to the information which he was friendly enough to give, several periods of folding and salt upthrust can be shown by angular discordances. A folding can be noticed very clearly between Lower and Upper Cretaceous (between Washita and Woodbine) which corresponds to the "Austrian" folding of Europe. It is shown in the profiles of the geological map of Arkansas, and will be further described by Spooner in *Bulletin 2* of the Arkansas Geological Survey. Another angular discordance representing a folding of "sub-Hercynian" age is found in Louisiana and Arkansas between Austin-Brownstown and Taylor. The Laramide revolution, too, seems to occur between Cretaceous and Lower Tertiary, and a considerable folding took place between Oligocene and Miocene ("Savian" folding of Europe).

Between these periods of orogeny and uplift occur the long periods of sedimentation, that is, of epeirogenic sinking of the region, and so we find in Louisiana, too, the upward (orogenic) movement and the downward (epeirogenic) movement of the subsurface, a kind of movement which has already been described for the German region of Saxonian structure.

The upthrust of the salt in these periods of orogeny seems to be proved by the fact that the transgressive horizons, for example the Lower or the Upper Cretaceous,[1] were locally deposited upon the salt.

In the opinion of Spooner, there is also in the salt-dome region of southern Louisiana and Texas more folding than is generally supposed. But as almost the whole folding is older than the younger Tertiary, it is concealed.

[1]W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), p. 217.

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BRYSON OIL FIELD, JACK COUNTY, TEXAS[1]

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ABSTRACT

The Bryson oil field, Jack County, Texas, was discovered in April, 1928, by the Panhandle Refining Company. Oil is produced chiefly from the Strawn formation, of Pennsylvanian age. The ultimate recovery from the field is estimated at 10,750,000 barrels, to be recovered from 1,300 proved acres, or an average of 7,500 barrels per acre. The gravity of the oil ranges from 40° to 42° Bé.

The accumulation of the oil is related to a series of lenticular sand bodies, folded into small anticlinal noses, with a northwest dip of 85 feet per mile. The major structure with which the Strawn beds of the Bryson field are associated is a monocline dipping northwest at the rate of 45 feet per mile. The regional feature known as the Bend flexure is a few miles west of the field.

LOCATION

The Bryson oil field is 11 miles north and 1 mile east of the southwest corner of Jack County, northern Texas. The extreme northern edge of the field is 3 miles north of Bryson and the southern edge is immediately north of the town.

INTRODUCTION

For several years Jack County was generally regarded by oil companies as possessing only a small productive possibility. During the past few years, however, test wells drilled by small companies and individuals have resulted in the discovery of several pools, the most important group of which compose the Bryson field.

The block in which the first well in the field was drilled was leased for the Panhandle Refining Company under the direction and supervision of J. P. Bowen. The initial well, the Panhandle Refining Company's W. A. Daugherty No. 1, was commenced on February 11, 1928, and completed on April 26, 1928, with an initial daily production of 240 barrels, swabbed from a sand found from 2,957 to 2,967 feet.

This well soon caused several other tests to be drilled. The second pool discovered in the field was drilled by The Texas Company and the

[1]Manuscript received, September 16, 1931.

[2]Manager, land and lease department, Panhandle Refining Company.

[3]Geologist, Panhandle Refining Company.

Petroleum Producers Company approximately 1½ miles southeast of the discovery well, and produced several hundred barrels per day from a lower sand after the "Panhandle Daugherty sand" had failed to produce. Development throughout the district then became very active and continued for the following two years.

By January 1, 1931, 84 wells had been drilled in the field, of which 75 were producers and 9 were dry holes. Most of the dry holes locate the defining limits of the pools. The very small percentage of failures within the field was due largely to the presence of several producing sand bodies. The field has not been fully developed: the west edge of the field has not been defined; many proved inside locations remain undrilled; and possibilities for deeper "pays" exist.

ACKNOWLEDGMENT

Information that was helpful in the preparation of this paper has been obtained from many sources during the past several years. Geologists acquainted with Jack County or the adjoining counties have been interviewed and their ideas and information incorporated. Information concerning the field has also been obtained from the field men of the companies operating in the district. Those to whom we are most indebted for information in assembling this report are M. G. Cheney, E. R. Newby, and D. E. Mathes.

TOPOGRAPHY AND DRAINAGE

The topography of the Bryson field area is rough, the relief being more than 200 feet. The predominating rocks are sandstones and the resulting topography, though not represented by cliffs, is extremely rough in many places.

Drainage, as a whole, is simple in pattern and is accomplished by means of steep-banked gullies which have an average gradient of 18 feet per mile in a southerly direction.

STRATIGRAPHY

The Graham formation of the Cisco group in the Pennsylvanian series forms the surface. The outcrops in the field are chiefly sandstone and shale beds, but the Gunsight limestone crops out in a part of the field.

The stratigraphic section, as revealed by drilling, is as follows, commencing at the surface. The Cisco group, occupying approximately 400 feet in the section, contains shale, sandstone, chert conglomerate, and limestone members. Shale and sandstone predominate.

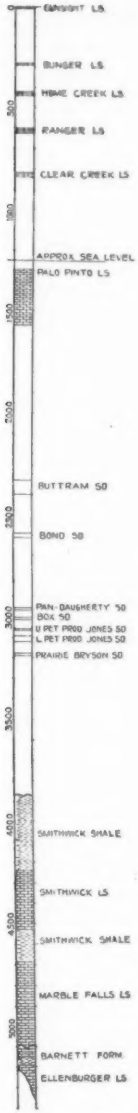

FIG. 1.—Stratigraphic section of Bryson field.

The Canyon group, consisting of four limestone members separated by shales, has a total thickness of 1,150 feet. The limestone members in the Canyon group are encountered in drilling in the following order: Home Creek, Ranger, Clear Creek, and Palo Pinto, the last including all the interval from the Palo Pinto to the Wiles limestone of southeast Stephens County.

The Strawn section, encountered underlying the Palo Pinto limestone, is represented by 2,300 feet of alternating limestones, shales, and sandstones. Shale predominates, although there are many sandstone members of importance as oil reservoirs. It is from the Strawn group that practically all of the oil is now being produced.

The Bend group is represented by the Smithwick and Marble Falls formations which are encountered as follows. The Smithwick formation, lying unconformably beneath the Strawn, has a thickness of 815 feet, consisting of an upper black shale 365 feet thick, a black and gray limestone 300 feet thick, and a lower black shale 150 feet thick. Below the Smithwick shale the Marble Falls formation is approximately 420 feet thick and includes a few thin shaly and sandy members locally, but is mostly gray and black limestone.

The Barnett formation, generally considered Mississippian in age, includes an undetermined thickness, but probably not more than 50 feet, of limestone, and a basal 30 feet of shale.

The Ellenburger limestone, of Cambro-Ordovician age, is found for an undetermined thickness beneath these Mississippian sediments.

PRODUCING HORIZONS

The "Panhandle Daugherty sand," at a depth of 2,950 feet in the west side of the field, the highest producing sand, is 10 feet in thickness, uniform in character, and has an initial maximum yield of 400 barrels per day.

The "Box sand" is 35 feet below the base of the "Panhandle Daugherty sand" and is approximately 1,715 feet below the top of the Palo Pinto limestone. It is represented by a sand thickness of less than 10 feet and the highest initial daily production that has been obtained from this sand is 100 barrels. Though this sand has not been proved productive in most of the wells, it offers a favorable opportunity for production by additional drilling. This sand is productive in the north end of the field.

The "Petroleum Producers Jones sand," 90 feet below the "Panhandle Daugherty sand," is a divided sand, the upper member, 10 feet in thickness, separated from the lower bed of 30 feet by a shale interval

which ranges from 5 to 40 feet in thickness. It is from this sand that most of the oil in the Bryson field is obtained at the present time. The initial production from this sand has been as large as 1,000 barrels per day.

Eighty feet below the top of the lower member of the "Petroleum Producers Jones sand," the Prairie Oil and Gas Company, in their Bryson No. 2, encountered a gas sand which yielded 13,000,000 cubic feet of gas per day. From this sand oil has been obtained in several of the wells farther north which were lower structurally.

The Petroleum Producers and The Texas Company, in their Shanafelt No. 1, on drilling 40 feet into the top of the Marble Falls limestone, encountered an oil sand which yielded an initial production of more than 1,000 barrels per day. The production in this well settled rapidly, and as no other wells favorably located have been drilled to this formation, the production from this horizon has been of small importance.

The producing sands are lenticular and the interval between them and the top of the Palo Pinto limestone differs throughout the field, due to an increased intensity of folding with depth. Because of this change in interval it is impossible to determine exactly which sand is encountered in a well by referring only to an interval. Both this interval and a survey of the logs of the adjoining wells is necessary to determine the exact sand drilled. The interval between the Palo Pinto limestone and the sands is nearly enough constant, however, so that a map contoured on top of the Palo Pinto limestone reflects the general structure of the underlying sandstone members.

NATURE OF PRODUCING SANDS

With the exception of one well, all oil in the field is produced from sands of the Strawn formation. The sands are lenticular throughout the entire field. The trend of the sand body varies in the different sands. The "Panhandle Daugherty sand" seems to extend from southwest to northeast across the main part of the field and to be productive on the sides of the field proper. The "Petroleum Producers Jones sand" was deposited in a north-south trend. The "Box sand" was very irregularly deposited and is found in different wells throughout the field. Drilling to date has shown the presence of the "Prairie Bryson sand" in the southeast part of the field and in the F. H. E. Oil Company's Leffel No. 5 in the extreme northern end of the field. The deep producer of The Texas Company and the Petroleum Producers on the Shanafelt land is located in the extreme southern end of the field. From the "Petroleum Producers Jones sand," along the crest of the anticlinal nose in the

center of the field, the largest amount of oil in the field has been produced.

By comparing several samples of sand in the Bryson field with cores of the Strawn formation on which S. Lomanitz, of Oklahoma City, had completed porosity tests, the average porosity of the sands in the pool was estimated at 18 per cent. These sands ranged in texture from coarse to fine, with the coarse sands predominating.

In the drilling of wells in the Bryson field it was found that, though some parts of the sands evidenced more productivity than others, there was an increase in the rate of production as additional sand was drilled, thus showing that the sands were generally productive throughout their entire thickness. This is contrary to many Strawn pools where a foot or two of sand seemed to provide all of the oil, and all other parts of the sand seemed non-prolific.

OIL RECOVERY

From the date of discovery until January 1, 1931, the gross production of the Bryson field amounted to 1,793,842 barrels. The monthly production mounted from 1,170 barrels in the discovery month of April, 1928, to the peak of 121,954 barrels in December, 1929. From this date production declined, partly because of a cessation of drilling caused by low crude prices. Proration of production due to reduced purchases by pipe-line companies, which had been made effective during the month of July, 1930, permitted production of only 26,691 barrels in December, 1930. If proration had not been placed on this production, it is probable that the monthly recovery at the end of 1930 would have been very near to 75,000 barrels.

At the end of 1929, 45 per cent of the field was drilled. In 1930 only an additional 15 per cent was drilled, making a total of 60 per cent of the pool developed at the end of the year. The remaining 40 per cent will contribute a considerable amount of oil and materially increase the recovery from the field.

In regard to the ultimate yield of the Strawn sands, an estimate has been placed at 5,000 barrels per acre if old methods of production are used. With the use of new methods, the ultimate yield should be increased 50 per cent, making an estimated average yield of 7,500 barrels per acre in the entire pool. The present limits of the pools include 1,050 acres, but the writers believe the area will be extended to 1,300 acres. It is therefore estimated that the production of 10,750,000 barrels ultimately will be recovered from the Bryson oil field.

STRUCTURE

The regional feature of the Bryson field is a northwest-dipping monocline. The Bend flexure, which is noticed in the pre-Strawn beds, extends nearly north and south, and is located a few miles west of the field.

The local structural conditions of the field have been fairly well determined by subsurface geology. The logs of all the wells have been

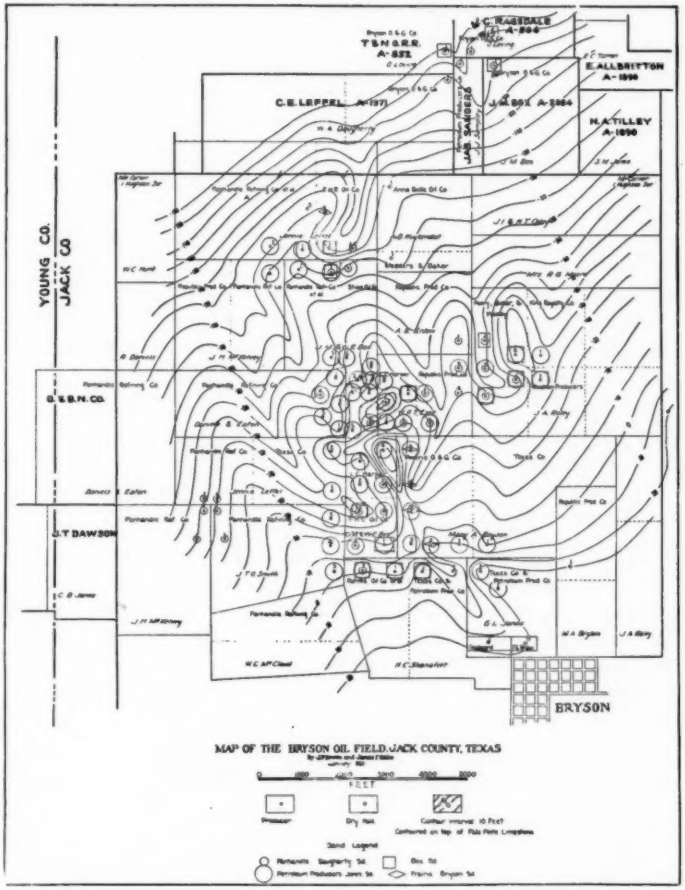

FIG 2

obtained and, by comparison, the distinctive markers have been selected. The Palo Pinto limestone seems to be the most consistent limestone and, as the top of this formation is the most regular marker that could be found in the field, it has been adopted as the datum plane on which the subsurface geology of the field is mapped. The top of the Palo Pinto limestone is readily identified in all wells drilled with cable tools and in most of the wells drilled with rotary tools. However, in some of the rotary tests, the top of the Palo Pinto limestone had to be determined by interpolation, which was fairly accurate because of other persistent limestone members in the section.

The subsurface structural map (Fig. 2), as constructed on top of the Palo Pinto limestone, reflects accurately the structure of the underlying producing sands. It shows a series of structural noses, the axes of which extend from southeast to northwest and dip approximately 85 feet per mile. This rate of dip, with a normal northwest dip for this region of 45 feet per mile, suggests that these noses are located on the northwest flank of a larger feature, such as a structural terrace in the district.

Though production is somewhat controlled by the structural features, such as these anticlinal noses, or possibly the wrinkling itself, the lensing of the sand bodies has probably been the main factor in the accumulation of oil in the Bryson field. Absence or thinning of sand bodies accounts for no production from some wells which were favorably located structurally. The wells in the south end of the field demonstrate this feature clearly. Figure 2 shows these features and the trend of the sand bodies.

QUALITY OF OIL

The gravity of the oil from the Bryson field ranges from 40° to 42° Bé. This is, in general, a higher gravity than that of the oil obtained from most of the other Strawn pools; consequently this should help in obtaining a larger recovery per acre.

An analysis of the average oil from the Bryson field is given as follows.

Gravity.....40° Bé.

	Per Cent
Basic sediment and water	.2
Sulphur	.23
Gasoline	40.0
Kerosene	10.8
Residuum	48.2
Losses	.57

The material boiling from the initial boiling point to 418° F. was considered gasoline, the material boiling from 418° to 500° F. was considered kerosene, and the material left in the still was residuum.

CONDITIONS OF PRODUCTION

The drilling methods include those of standard and rotary tools. The supporters of each method find justification for their method and the drilling of this field has been almost equally divided between the two methods.

The cost of drilling and equipping a well in the field ranges from $20,000 to $35,000; most of the wells cost approximately $30,000. The time necessary to drill a well and complete it to the tanks ranges from 45 to 60 days.

As the average depth of the wells is 3,000 feet, and as they must be pumped after the pressure declines, the pumping cost is a factor that must be considered. Many of the wells are equipped with ordinary pumps; others, with air lift. Central pumping plants, whereby several wells can be pumped by the same engine, are also used and considerably lower the lifting costs.

POSSIBILITIES OF DEEP PRODUCTION

The possibility of obtaining oil from formations deeper than the Strawn was assured when The Texas Company and the Petroleum Producers' Shanafelt No. 1 was drilled into the top of the Marble Falls limestone and a production of 1,000 barrels daily was obtained. Although the production in this well settled rapidly, it evidenced the fact that the deeper horizons possessed very favorable chances for oil to be produced from wells which were properly located. No other wells have been drilled to this horizon in a well selected area and the results to be obtained for this horizon must be awaited.

Although the overlying Smithwick formation has been tested in two wells in the Bryson area and no oil encountered in either, it possesses some chance for production, as it is productive in several near-by counties.

The Ellenburger limestone (which may be considered the basement limestone in north-central Texas) has yielded oil in several isolated places and it may prove of value in this area. As the top of the Ellenburger limestone would be encountered below 5,000 feet, it is probable that unfavorable economic conditions will prevent these deeper formations from being drilled for some time.

The area most favorable for producing deeper oil seems to be north and west of the present producing area. W. K. Esgen states:[1]

> structure in the Bend commonly shifts down-dip from surface structure, and accumulation is ordinarily found some distance down-dip from its theoretical location, as judged from surface folding.

The Strawn structural conditions are very closely revealed by the structure of the Palo Pinto limestone and it is reasonable to suppose that structural features in the deeper beds are down-dip from corresponding features in the shallower strata.

TABLE I

MONTHLY PRODUCTION OF BRYSON POOL (IN BARRELS)

1928	
April	1,170
May	4,650
June	4,200
July	4,960
August	16,430
September	14,250
October	15,810
November	15,300
December	21,390
1929	
January	27,032
February	21,280
March	21,386
April	36,990
May	54,374
June	74,580
July	91,295
August	97,464
September	91,170
October	95,418
November	101,431
December	121,954
1930	
January	108,139
February	99,092
March	101,184
April	90,300
May	84,568
June	77,340
July	61,387
August	82,577
September	51,990
October	42,160
November	35,880
December	26,691
Total production	1,793,842

[1]W. K. Esgen, "Relation of Accumulation of Petroleum to Structure in Stephens County, Texas." *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), p. 477.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 189-204, 4 FIGS.

STRUCTURAL AND STRATIGRAPHIC DEVELOPMENT OF SOUTH PERMIAN BASIN, WEST TEXAS[1]

R. L. CANNON and JOE CANNON[2]
San Angelo, Texas

ABSTRACT

The rocks of the several stages of the Permian are differentiated by a study of the successive periods of deformation during the down-warping of the South Permian basin. The greatest period of diastrophism, which occurred at the end of Clear Fork time, and the unconformity resulting, are used as a regional key to correlation. The widely accepted faunal-reef theory of the origin of the thick limestone masses is questioned. The theory of precipitation of calcium carbonate and calcium magnesium carbonate in shallow waters is offered as the principal source of this limestone. The term "limestone," as used in this paper, includes dolomite. The structural features in the Permian rocks are principally flexures resulting from downwarping of the more negative areas during the accumulation of the sediments.

INTRODUCTION

The writers are indebted to almost all the oil companies operating in the area for their generosity in permitting the examination of well samples. They wish to express their appreciation of the helpful suggestions of W. A. Maley, Frank E. Lewis, Cary P. Butcher, Robert E. Rettger, Lon D. Cartwright, Robert I. Roth, Joseph E. Morero, C. L. Mohr, P. A. Schlosser, and H. P. Bybee.

This paper is the result of an effort of the writers to segregate the several formations of the Permian in the south part of the basin by tracing the history of the successive deformations. If given sufficient time and material, sediments tend to fill a basin. Successive subsidences, or continuous subsidence, are thus necessary to permit the further accumulation of sediment. With each succeeding downwarp come rearrangements of shore lines and depths of water. These in turn leave their imprints in the distribution, thickness, and type of sediments.

Two kinds of subsidence are recorded in the sediments of the South Permian basin of West Texas: gradual and abrupt. Gradual subsidence occurred in the Delaware Mountain basin throughout a long period of time, permitting 3,500 feet of Delaware Mountain beds to be deposited.

[1]Read by title before the Association at the San Antonio meeting, March 20, 1931. Manuscript received, October 9, 1931.

[2]Petroleum geologists, 505 San Angelo National Bank Building.

Abrupt subsidence resulted in the termination of the deposition of these sediments. At the time of greater downwarp in the more negative areas the more positive areas rose to some extent.

Three cross sections are presented showing the correlations. Figure 1 extends from western Edwards County north and west to south-central Midland County. Figure 2 extends across the south part of the Permian basin from the northeast corner of Schleicher County west to the north corner of Brewster County. Figure 3 shows a cross section approximately parallel with the section shown in Figure 2 and extending from the east side of Runnels County to the north-central part of Culberson County. Figure 4 is a map showing the south and east limits of sediments of three formations in the Permian and areas of thick limestone masses in the Lower Permian.

EARLY CARBONIFEROUS BASINS

Cheney[1] has shown that the earliest Carboniferous sediments were deposited in narrow, trough-like basins. He shows the Ouachita sediments (chiefly Mississippian) in central Texas as attaining their maximum thickness (10,000 feet) in the most eastern trough of Carboniferous deposits. The succeeding sediments, of Pottsville age, were thickest (5,000 feet) in a trough generally parallel with, but slightly west of, the earlier Ouachita trough. The Allegheny likewise shows an area of greatest thickness (3,000 feet) slightly west of that of the Pottsville. The Canyon and Upper Strawn attained their greatest thickness (1,500 feet) slightly west of the Allegheny. The succeeding member of the Pennsylvanian is grouped in this paper with the overlying Lower Permian, which has a much wider basin of deposition.

The result shown is a progressive thinning of total Pennsylvanian sediments from the trough area of the Pottsville westward toward the Permian basin.

Sellards[2] shows the position of the sediments of the Ouachita facies from the Ouachita Mountains in southern Oklahoma southwestward to the Marathon area of Texas. He shows this basin as near or immediately adjacent to the northwest margin of Llanoria and immediately north of Columbia. The younger Pennsylvanian basins may logically be expected to lie in succession in the same order northward from the

[1]M. G. Cheney, "History of the Carboniferous Sediments of the Mid-Continent Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 557-94.

[2]E. H. Sellards, "Map of Paleozoic of Ouachita Facies," "Advance publication from Hand Book of the Stratigraphy of Texas," *Univ. Texas Bull.* (1930).

Ouachita basin north of Columbia as they lie westward from this basin in the northeast area.

This is the assumption of the writers of this paper shown in the cross section presented in Figure 1. The lower sand-containing section, which thins greatly northward, is regarded as Pennsylvanian, conforming to our present conception of the thinning of total Pennsylvanian sediments northward and westward from the Ouachita basin. The sediments immediately above this northward-thinning, sand-containing section show a marked uniformity of characteristics and thicken toward the center of the Permian basin. These are, therefore, regarded as Permian in age. This is in agreement with the identification by Dunbar[1] of Wolfcamp fossils in the lower part of this section at depths between 7,689 feet and 7,701 feet in the Big Lake Oil Company's University No. 1-C, Reagan County. Figure 3 shows a continuation of the westward thinning of total Pennsylvanian sediments formerly pointed out by Cheney.

PERMIAN SEDIMENTS

Extensive work by W. A. Maley at the outcrop in McCulloch County in 1928 did not reveal evidence of an unconformity between beds of Cisco age and those of the overlying Wichita-Albany. C. L. Mohr has seen coarse limestone conglomerate at this horizon a few miles south of Coleman Junction in Coleman County. Nevertheless, any unconformity which may occur at this horizon is not noticeable in McCulloch County. However, 700 feet below the contact between rocks of these two series there is an unconformity. It is marked by a conglomerate horizon which in many places overlaps older strata. This conglomerate horizon is at the base of the Waldrip beds of Drake.[2] M. G. Cheney[3] mentions occurrence of coarse conglomerate in the Cisco farther north. It is the impression of the writers that the base of the conglomerate-containing section in the north area is in the same relative position in the Cisco as that in McCulloch County.

This appearance of conglomerate and the associated unconformity is regarded by the writers as marking the time of the downwarping which

[1]E. H. Sellards, H. P. Bybee, and H. A. Hemphill, "Producing Horizons in the Big Lake Oil Field, Reagan County, Texas," *Univ. Texas Bull. 3001* (September, 1930), p. 154.

[2]N. F. Drake, "The Colorado Coal Fields of Texas," *Texas Geol. Survey 4th Ann. Rept.* Later reprinted as *Univ. Texas Bull. 1755* (1917).

[3]M. G. Cheney, "Stratigraphic and Structural Studies in North Central Texas," *Univ. Texas Bull. 2913* (1929).

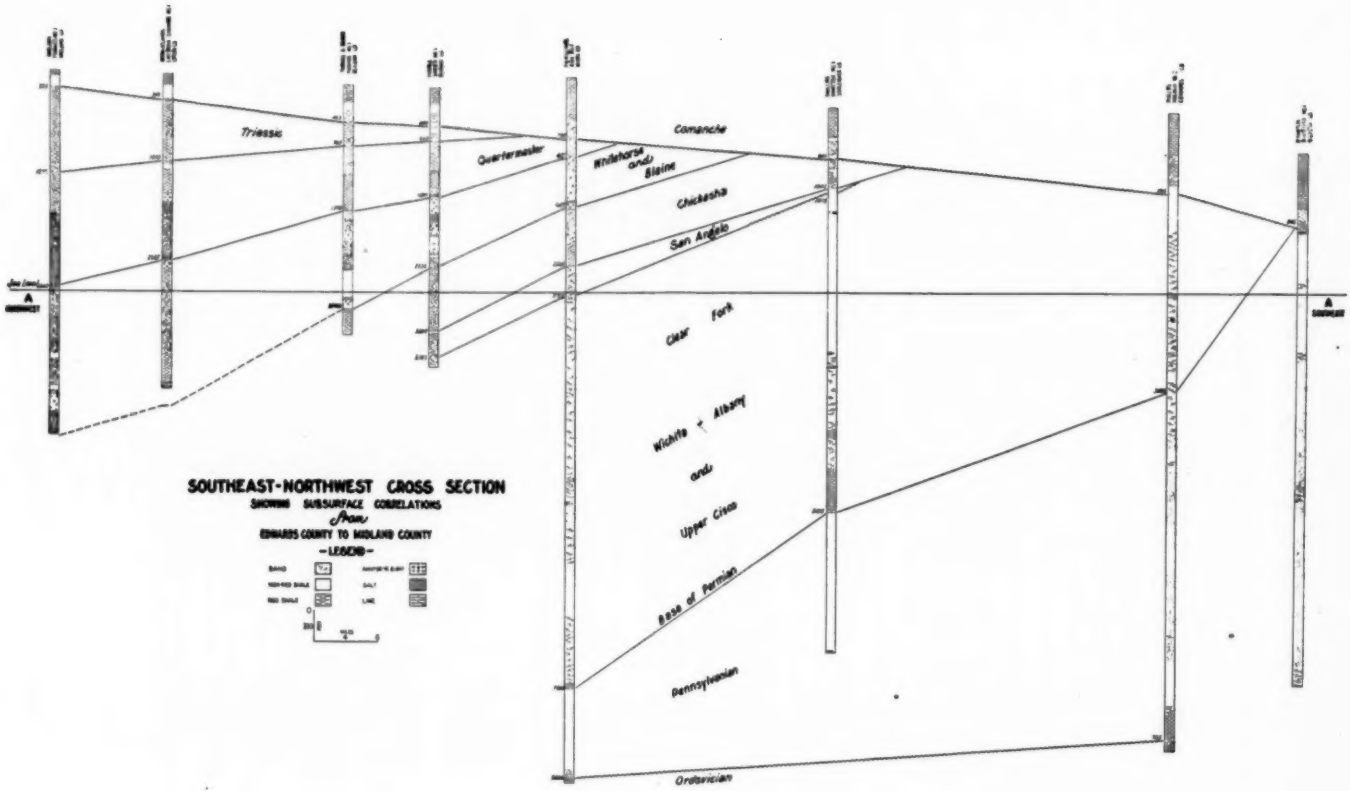
Triassic
Quartermaster
Whitehorse and Blaine
Comanche
Chickasha
San Angelo
Clear Fork
Wichita + Albany and Upper Cisco
Base of Permian
Pennsylvanian
Ordovician
SOUTHEAST-NORTHWEST CROSS SECTION
SHOWING SUBSURFACE CORRELATIONS
from
EDWARDS COUNTY TO MIDLAND COUNTY
-LEGEND-

FIG. 1

resulted in the creation of the Permian basin. This conformity of Upper Cisco with the overlying Wichita-Albany suggests that the base of the Permian should probably be placed at the unconformity in Lower Cisco, rather than at the present generally accepted horizon at the base of the Wichita-Albany.

In answer to a letter of inquiry regarding this determination, Robert I. Roth confirms this conclusion on paleontological evidence. He further states that the Upper Cisco and part of the lower Wichita-Albany, in a general way, are correlative with the Wolfcamp of the Glass Mountain section.

It seems more probable, however, that the top of the Cisco corresponds with the top of the Wolfcamp. There is a decided change in type of material at the top of the Cisco and an unconformity at the top of the Wolfcamp.

No definite break for the top of the Upper Cisco-Wolfcamp section is recognized by the writers in either the Main Permian basin or the Delaware Mountain basin. However, the south part of the Central Basin platform has a definite break at the top of what seems to be this stage. The Sun Oil Company's Scott No. 1, Terrell County, entered a section at 3,250 feet which seems to be typical Upper Cisco. Similar beds were penetrated in the Shell-Humphreys' University No. 1 on the Fort Stockton "high," Pecos County, between the depths of 4,250 feet and 4,745 feet.

FIG. 1

WICHITA-ALBANY AND CLEAR FORK SERIES

At the beginning of Wichita-Albany time, certain definite limestone-depositing areas and other clastic-depositing areas were established in the South Permian basin. These limestone areas tended to remain positive throughout Permian time (as is pointed out later). It is, therefore, probable that they became positive at the beginning of Wichita-Albany time.

Inasmuch as there is considerable similarity of sediments in the Wichita-Albany and Clear Fork in much of the South Permian basin, these two series are herein first considered together.

During these two epochs, limestone was the principal sediment on the southwest and northwest rim areas of the Eastern platform. Farther east, toward the margin of the basin, the clastic content of the sediments increased rapidly. In the south part of the Main Permian basin these sediments are principally black shale with some fine sand. On the main part of the Central Basin platform, so far as is known, limestone

was deposited almost exclusively. In the southern extension of this platform in Terrell County, some clastics were deposited. This would be expected in the shoreward part of this platform area. In the Delaware Mountain basin the sediments are principally clastic. On the Western platform the sediments are chiefly limestone. At the end, or near the end, of Clear Fork time, deposition was interrupted in wide areas.

The Clear Fork epoch culminated in perhaps the greatest diastrophism of the Permian basin. As is more clearly pointed out in the treatment of the San Angelo stage, the sea was greatly restricted on the south and the platform areas were subjected to erosion for a considerable period of time. A movement of this kind should leave its impress on the sediments of all depositing areas. The most outstanding break in deposition known in the South Permian basin area is that at the top of the Delaware Mountain formation, in the Delaware Mountain basin. Prior to the end of the deposition of the Delaware Mountain sediments, well sorted and stratified sand, shale, and a less amount of limestone were deposited throughout a wide area. Thereafter, only anhydrite, salt, and small amounts of limestone were deposited. This, the greatest break in the Delaware Mountain basin, is undoubtedly to be connected with the greatest period of diastrophism known in the basin. Inasmuch as the greatest unconformity in the south part of the Main Permian basin occurred between the Clear Fork and the overlying beds, it is very probable that the top of the Delaware Mountain formation is equivalent in age to the top of the Clear Fork (Fig. 2).

It has long been known that the top of the Delaware Mountain formation corresponds approximately with the top of the Word formation in the Glass Mountains area.

From the foregoing correlations it seems that the top of the Wichita-Albany corresponds with the top of the Bone Springs and the top of the Hess-Leonard; that the Hess and Leonard are two facies of time equivalents has been pointed out to the writers by Frank E. Lewis.

SAN ANGELO STAGE

That there is an unconformity between the San Angelo stage and the underlying beds was mentioned by Lerch,[1] who originally described this stage.

Beede and Bentley[2] state that the rocks of the San Angelo formation lie unconformably on those of the Clear Fork. They state that there is

[1]Otto Lerch, *American Geol.*, Vol. 7 (1891), pp. 74-77.

[2]J. W. Beede and W. P. Bentley, "The Geology of Coke County," *Univ. Texas Bull. 1850* (September, 1918).

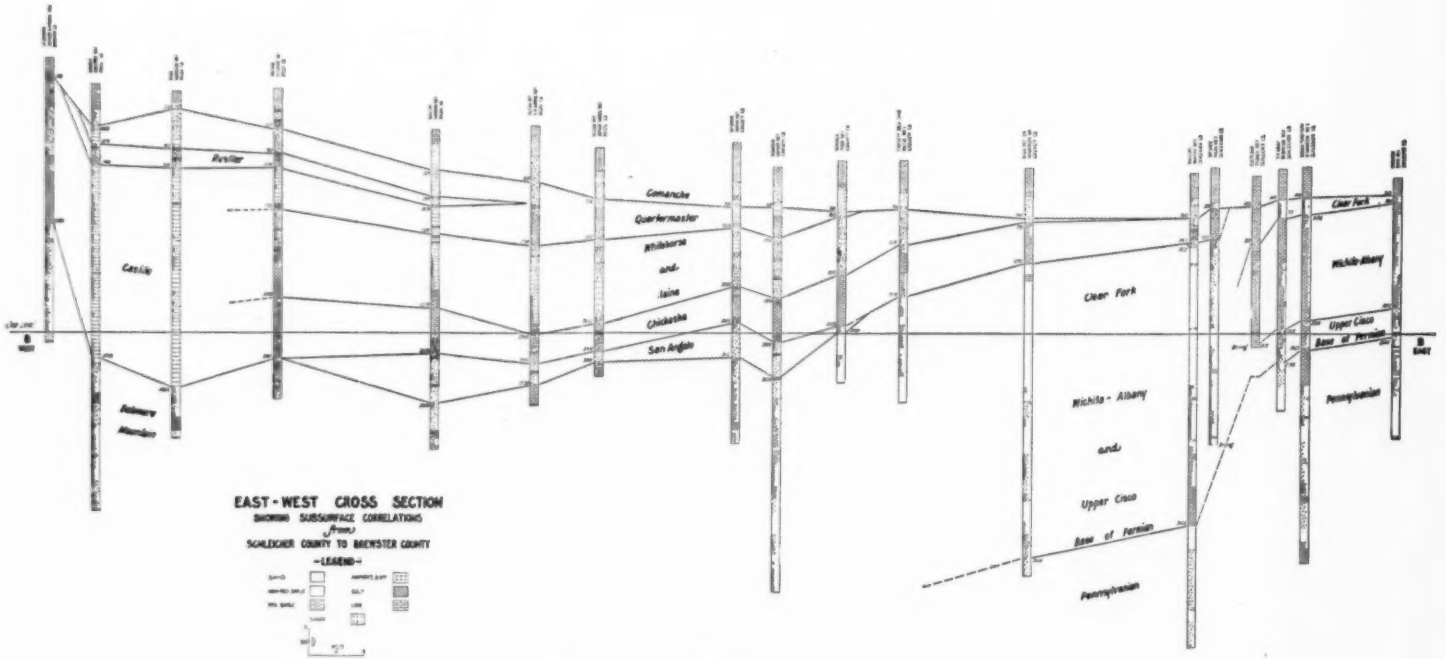
Comanche
Quartermaster
Whitehorse
and
Ione
Chickasha
San Angelo
Clear Fork
Wichita - Albany
and
Upper Cisco
Base of Permian
Pennsylvanian
Clear Fork
Wichita-Albany
Upper Cisco
Base of Permian
Pennsylvanian
Arvilla
Cazzle
Antony
Hamlin
EAST - WEST CROSS SECTION
SHOWING SUBSURFACE CORRELATIONS
from
SCHLEICHER COUNTY TO BREWSTER COUNTY
-LEGEND-

FIG. 2

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[1]Otto Lerch, *American Geol.*, Vol. 7 (1891), pp. 74-77.

[2]J. W. Beede and W. P. Bentley, "The Geology of Coke County," *Univ. Texas Bull. 1850* (September, 1918).

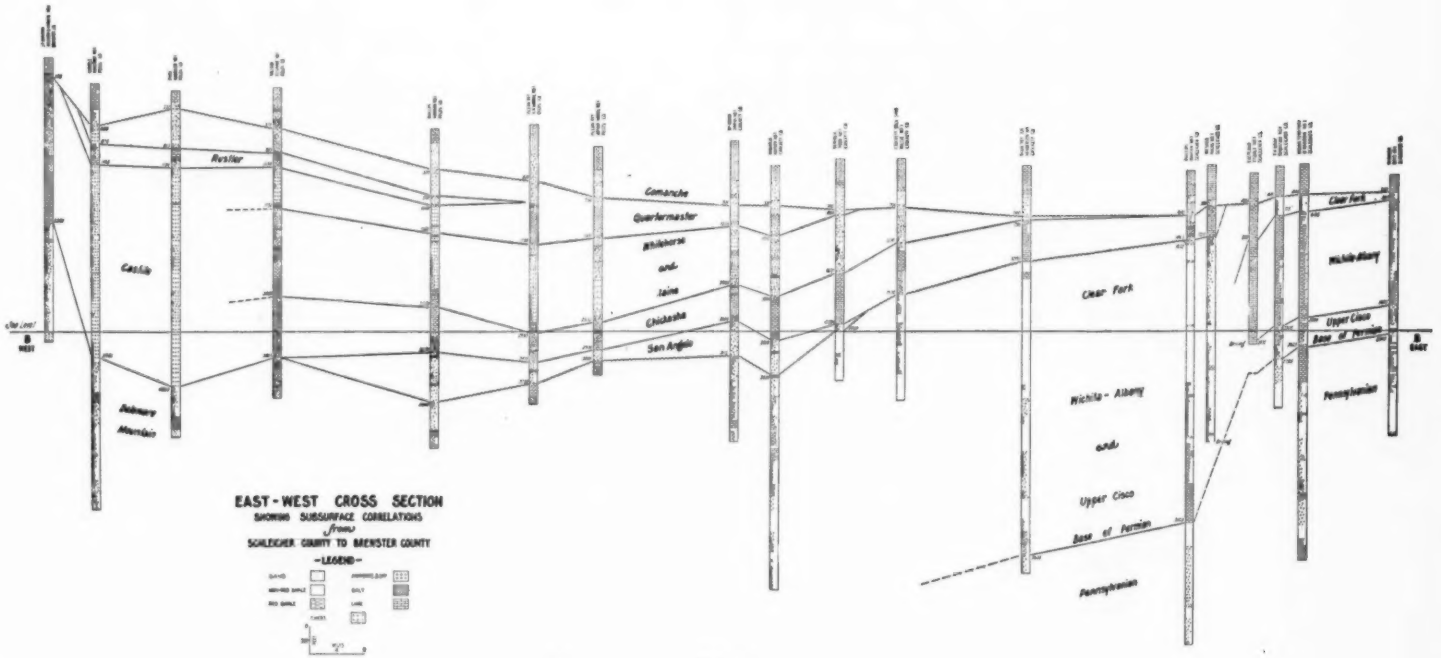
Rustler
Castle
Salado
Artesia
Comanche
Guadalupe
Whitehorse
and
Leine
Chickasha
San Angelo
Clear Fork
Wichita - Albany
and
Upper Cisco
Base of Permian
Pennsylvanian
Clear Fork
Wichita-Albany
Upper Cisco
Base of Permian
Pennsylvanian
EAST - WEST CROSS SECTION
SHOWING SUBSURFACE CORRELATIONS
from
SCHLEICHER COUNTY TO BREWSTER COUNTY
-LEGEND-

FIG. 2

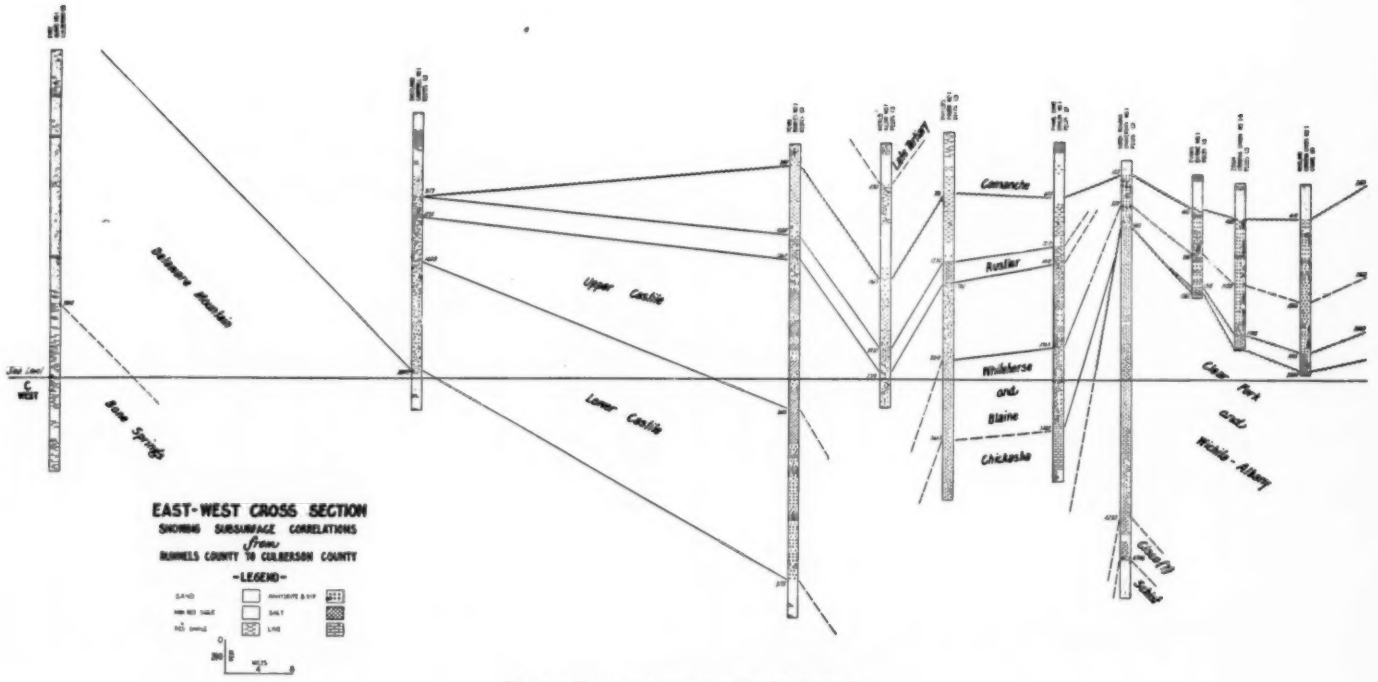

FIG 3.—East-west cross section (west part).

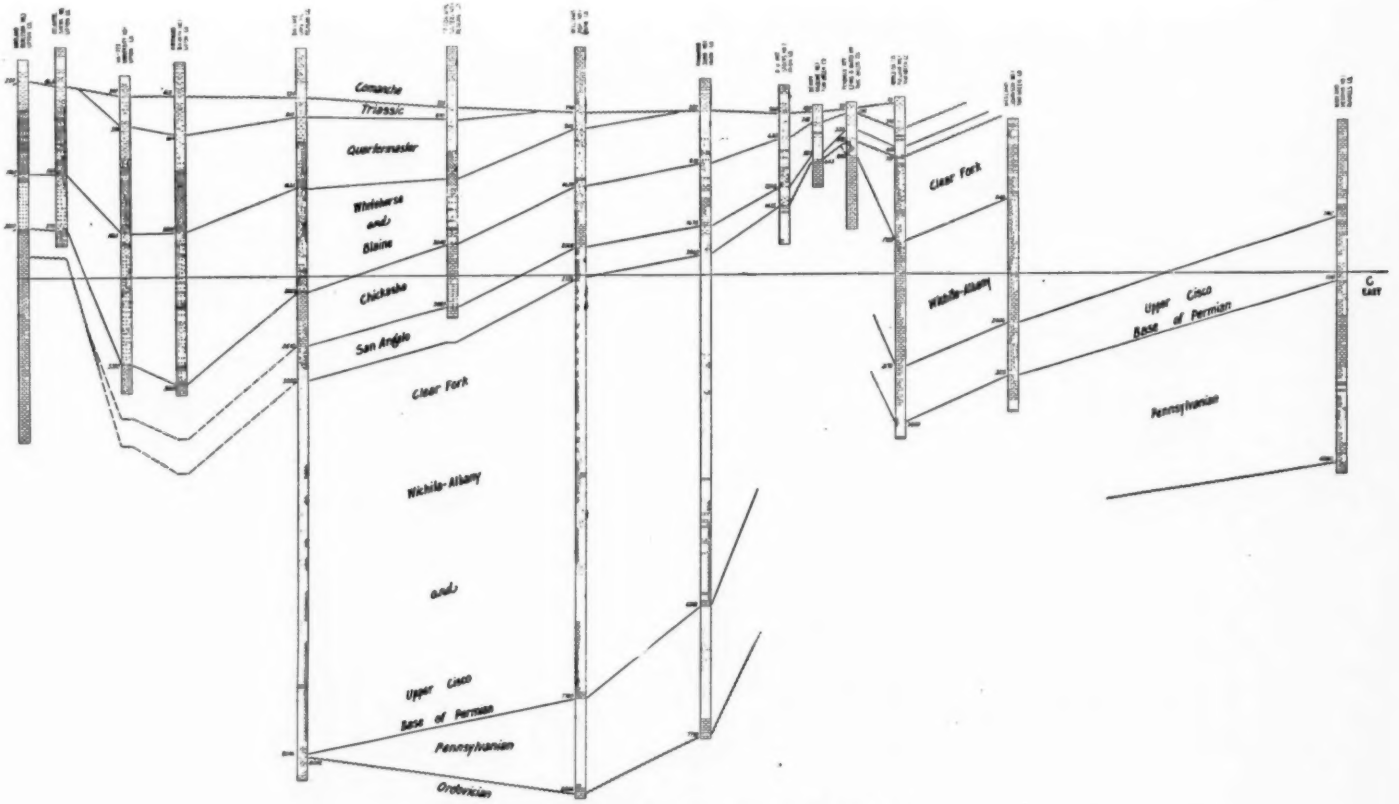

FIG. 3 (continued).—East-west cross section (east part)

an interval of 270 feet of rocks between the San Angelo and the Merkel dolomite along Colorado River, though along the Texas and Pacific Railroad the interval is only 25 feet.

Other authors have recognized this unconformity. Its wide extent and consequent importance can not be too greatly stressed.

In early San Angelo time the basin was greatly restricted on the east and south. The Eastern platform was above water and subjected to considerable erosion (Fig. 3). Inasmuch as the San Angelo sea did not cover all the Sheffield channel (Fig. 4), it undoubtedly never covered the Central Basin platform. This is borne out by the absence of San Angelo material in the southern part of this platform as shqwn in cross section *CC* (Fig. 3). Late in San Angelo time, the sea transgressed the Eastern platform (Fig. 4), but the extreme coarseness of the San Angelo conglomerate at the outcrop and the fact that it grades within a short distance down-dip into finer materials, indicate that the strand line was near the position of the present outcrop.

The San Angelo attains an average thickness of 500 feet in the Main Permian basin and in the north part of the Sheffield channel. In these areas it is composed chiefly of medium to fairly coarse sandstone with shale and some limestone. At the outcrop, the average thickness is approximately 110 feet. Here the materials are coarse conglomerate, sand, and shale. In the Delaware Mountain basin the sediments of this stage are anhydrite and salt (Fig. 2). In the Glass Mountains this age is probably represented by a hiatus between the Word and the Vidrio. The position of the San Angelo strand line in the Sheffield channel area suggests that the sea did not extend as far south as the Glass Mountains area during this time. A similar hiatus probably occurs on the Western platform.

CHICKASHA STAGE

At the outcrop in Tom Green, Coke, and northwest Taylor counties, there is an interval of an average thickness of 220 feet composed principally of red shale with less amounts of green shale and sandstone. In the upper 75 feet of this member there are a few beds of thin limestone containing fossils. Immediately overlying this 220 feet of section there is a sandstone and conglomerate bed with a maximum thickness of 50 feet.

This predominantly red shale section immediately overlies the San Angelo stage. At the outcrop, the contact between the two is gradational. As this member lies directly above the San Angelo it corresponds with the Chickasha stage of Oklahoma.

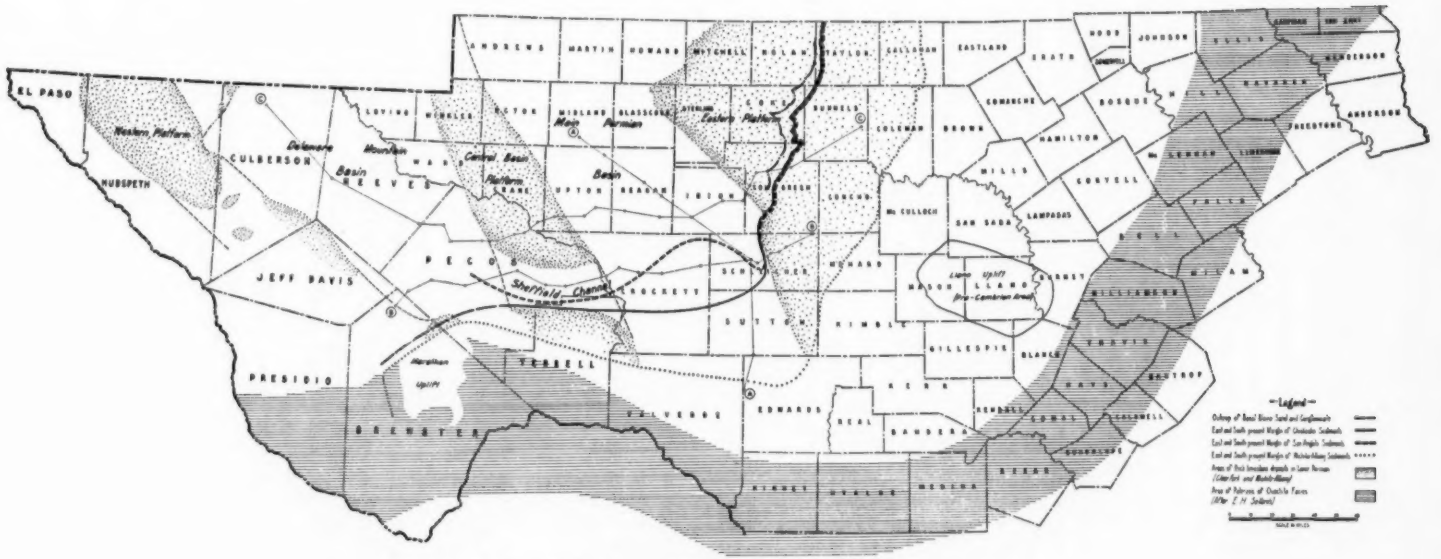

FIG. 4.—Geologic map of South Permian basin, West Texas.

Lloyd and Thompson[1] mention this member as being recognizable in most places, though not especially outstanding. They, therefore, treat this stage as part of the Blaine. C. N. Gould, in a discussion following the reading of Lloyd and Thompson's paper, objected to the treatment of the Chickasha as a part of the Blaine. At the outcrop, on the east side of the basin (in the area discussed in this paper) this member is well marked. The basal Blaine conglomerate immediately overlies it.

Beede and Bentley[2] referred all the section from the base of the San Angelo stage to the top of the basal Blaine conglomerate to the San Angelo formation.

Beede and Christner[3] placed the beds of the Chickasha stage in the Blaine (as did Lloyd and Thompson).

In the south part of the Main Permian basin, in the Sheffield channel, in the south rim areas of the Delaware Mountain basin, and on a large part of the Central Basin platform, the Chickasha is composed largely of limestone (Figs. 1, 2, and 3).

In early Chickasha time the sea transgressed southward over areas in the south part of the Main Permian basin and the Sheffield channel that had been land in San Angelo time (Fig. 4). A large part of the Central Basin platform was also subject to deposition during part, at least, of this age (Fig. 2).

In the Glass Mountains, the base of the Vidrio is probably correlative with lower or basal Chickasha. The transgression of the sea again permitted deposition in this area.

In the Delaware Mountain basin the Chickasha is composed chiefly of anhydrite with some salt.

BLAINE-WHITEHORSE STAGE

Inasmuch as no definite traceable breaks are recognized by the writers in the section between the base of the Blaine and the base of the Quartermaster, the Blaine, Dog Creek, Whitehorse, and Cloudchief are herein treated as the Blaine-Whitehorse stage.

The Chickasha culminated with a period of deformation. The evidences of this deformation are: (1) coarse conglomerate in basal Blaine

[1]A. M. Lloyd and W. C. Thompson, "Correlation of Permian Outcrops on Eastern Side of the West Texas Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), p. 950.

[2]J. W. Beede and W. P. Bentley, *op. cit.*

[3]J. W. Beede and D. D. Christner, "The San Angelo Formation, The Geology of Foard County," *Univ. Texas Bull. 2607* (February, 1926).

at the outcrop in Tom Green, Coke, and Nolan counties, (2) gravel in basal Blaine in southwest Crockett County, and (3) abrupt change in sediments from limestone in the Chickasha to sand, anhydrite, and salt in the Blaine in the southern part of the Main Permian basin.

The sediments of this stage are chiefly sand, red shale, and anhydrite on the Eastern platform. There is some limestone in the section in Howard and Glasscock counties. Some salt occurs in these beds in north-central Sterling County and in Mitchell County.

The sediments of this stage in the Main Permian basin are similar to those of the Eastern platform except that the total thickness is much greater and that there is an increase in salt.

In the Delaware Mountain basin proper, this member is composed of anhydrite, salt, and a little limestone. On the rim areas, on the west, south, and east, considerable limestone was deposited (Fig. 2).

Along the west rim of the Central Basin platform considerable limestone and sandstone were deposited. These sediments pinch out within short distances eastward, giving place to anhydrite. The Fort Stockton "high" was probably above water during the early part of this age.

QUARTERMASTER STAGE

That there was deformation at the end of Blaine-Whitehorse time is indicated in two ways. 1. Limestone ceased to be an important part of the sediment with the end of this age, indicating that the connection with the sea was nearly or completely broken. 2. The cross section of the succeeding sediments (across the basin from margin to margin) shows the lower limit much more downwarped than the upper. The sediments tended to fill the pre-existing depressions as they did in all preceding stages.

The fact that the upper main salt grades into typical Quartermaster red sandy shale in the margin areas, indicates that this salt is a part of the Quartermaster stage. Like the salt of the prior Blaine-Whitehorse stage, this salt was deposited in greatest thicknesses in the more basinward areas. In this connection it is well to point out that the deformation at the end of Blaine-Whitehorse time depressed the north and east part of the Central Basin platform almost, if not quite, as much as it did the Main Permian basin. This is shown by the approximately constant thickness of the main salt in the two areas. A greater thickness of salt in the east-central part of the Delaware Mountain basin indicates greater depression for that area.

Following the salt deposition in the Main Permian basin and on a large part of the Central Basin platform, there was deposited a thin, but

variable, section of anhydrite. In the Delaware Mountain basin this anhydrite section is much thicker. In it there is a limestone member (the Rustler). This member is thickest near the west and south rim areas.

Succeeding this anhydrite-limestone member, there is a section of red shale containing some sand which was probably deposited in the entire central part of the basin. In the Delaware Mountain basin there is as much as 800 feet of this section. In the Main Permian basin the maximum thickness is approximately 500 feet.

GENERAL DISCUSSION OF VARIOUS FACIES OF TIME EQUIVALENCY

As mentioned in the preceding correlations, massive limestone sections were deposited in the Lower Permian in shallow water during the time of thicker deposition of clastics in relatively deeper water. Faunal reef origin of such limestone masses has been proposed by Lloyd[1] and others.

It is more probable, however, that although limestone formed by reef-forming organisms doubtless contributed to the growth of these limestone masses, such origin is probably of secondary rather than of primary importance. This seems evident because of the fact that anhydrite and salt were deposited in Upper Permian time in the deeper parts of the basin at the same time that limestone was being deposited in the shallower water.

The existence of thick limestone masses deposited in shallow-water areas is very probably largely due to rapid precipitation in warm, near-surface water. Areas of such environment were of course most favorable to the growth of lime-shell animals. Consequently their tests added to the accumulating lime.

The scarcity or absence of clastics in these masses, at times of clastic deposition in near-by somewhat deeper-water areas, is doubtless due to the fact that the chief transporting agent was wave action. The South Permian basin was so interspersed with barriers that currents were probably of small transporting consequence. Wave action in depths not exceeding 600 feet tends to distribute sediments over entire basins until such time as the accumulated materials reach a certain gradient, dependent on the width of the body of water. Any offshore area higher than such a gradient of deposition could not receive clastics. These areas, having shallow, warm waters, did, however, receive precipitated limestone

[1] E. Russell Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645-58.

and tests of organisms. Some newly precipitated limestone in such areas tended to be removed by wave action. Much so removed was deposited in inclined sheets adjoining the shallow-water areas.

In the deep, lower water of this basin, the temperature was lower. Temperature decreases with depth. Though limestone is precipitated out of warm water and redissolved in cold water, the reverse is true for salt and anhydrite. More salt or anhydrite can be carried in solution in warm water than in cold. The deep, cold water would therefore precipitate salt and anhydrite at concentrations that would not have resulted in precipitation in warmer water. In the absence of currents, and at depths too great for wave action, precipitants only could have formed important parts of the sediments. From this consideration the writers offer the theory that salt and anhydrite in the Permian basin are not products of complete desiccation, but are rather the products of precipitation from deep, cold water in partly desiccated seas. This explains the many lenses of salt and anhydrite which are thickest in the deepest basin areas and pinch out completely marginward. The thickest lenses of salt and anhydrite were deposited in the greater negative areas. They were deposited at times when continuous deposition shows that the basin extended far out from these areas of precipitation.

The fact that the greatest thicknesses of salt in the South Permian basin are found in the most negative areas is *prima facie* evidence that it was precipitated from the deepest water then present. With the shallowing of the most negative areas by the filling up with sediments to shallow-water depths came the complete end of salt deposition. Thence followed transition upward from salt to anhydrite in the main Permian basin and from salt to anhydrite and limestone in the Delaware Mountain basin. Subsequently, in the resulting shallow water, a layer of red, sandy shale was deposited in the entire basin. Thus, it becomes clear that during the deposition of salt and anhydrite, the precipitation of these products was restricted to the deep-water areas; also, that when water became shallow in these areas, because of the accumulation of precipitants, salt and anhydrite ceased to be precipitated. This change in deposition from precipitates to clastics was not a result of freshening of the water, because, had this occurred succeeding the period of clastic deposition, there should have been a final desiccation stage in which all the salt and anhydrite in solution would have been precipitated. No salt or anhydrite is known in the South Permian basin area above the upper Quartermaster red sandy shales.

STRUCTURE

The structurally "high" features of the South Permian basin should be termed flexures when referring to the deformation shown in Permian strata. The many downwarps of the more negative areas each flexed the previously deposited Permian beds over the edges of the positive features. As a result, the amount of deformation increases as successively older beds are considered. The total southwest dip on the top of the Chickasha for a distance of 13 miles is 591 feet as measured in eastern Irion County down the southwest flank of the Eastern platform. The corresponding dip on the base of the San Angelo is 1,306 feet. In Schleicher County, where information is available on lower beds, the corresponding dip on the base of the Permian is 3,166 feet. Similar variations in dip for rocks of the several stages occur on the flanks of each of the other platforms.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 205-215, 6 FIGS.

GEOLOGICAL NOTES

SOUTHWARD EXTENSION OF BONHAM CLAY, TEXAS

The Austin formation, in its type area near Austin, Travis County, Texas, consists, as the common association of the term "chalk" with the formation name suggests, of white, chalky limestone, with thin seams of calcareous marl. This description characterizes the lithology of the formation not only in the Austin area, but as far north as McKinney, Collin County, Texas.

L. W. Stephenson[1] in 1918 described the Bonham clay, a thick, slightly calcareous clay member of the Austin, as the formation is developed in northeastern Texas. He states[2] that in eastern Grayson and western Fannin counties, approximately the lower one-half of the formation consists of "impure argillaceous chalk and slightly chalky clay marls . . ." He did not trace the Bonham clay west or south of central Grayson County, but believed that the clay merged westward and southward with typical Austin chalk, this merging occurring "gradually through considerable linear distance." He does not indicate how great he supposed this linear distance to be.

The present writers, in the spring of 1931, while engaged in a search for clay seams in the Austin formation of north Texas for the purpose of securing samples for micropaleontological studies, observed a layer of grayish-to-yellowish, moderately calcareous clay of considerable thickness in an excellent exposure 3.1 miles west of the courthouse square at McKinney. The senior writer, on the supposition that this marl seam, exceptionally extensive and exceptionally soft and argillaceous for the Austin of this area, might be a southward extension of Stephenson's Bonham clay, later attempted to discover the clay member in northern Collin and southern Grayson counties, and to trace it southward from its exposure west of McKinney.

Marls of the lithologic character described in the preceding paragraphs were found to crop out in a strip approximately 2 miles wide, west of the city of Van Alstyne, just north of the Collin-Grayson county

[1] "A Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U. S. Geol. Survey Prof. Paper 120-H* (1918), p. 150.

[2] *Idem*, p. 148.

line. The marl thus forms a member of considerable thickness in this area. Exposures of similar beds were observed in the vicinity of Howe, between Van Alstyne and Sherman. Search failed to reveal beds of clay of any considerable thickness south of McKinney.

It seems probable that the clays observed and here described represent a southward extension of the Bonham clay, which is thus traceable as a distinct member as far south as McKinney, Texas. The member becomes gradually thinner throughout its southern extension, merging into the chalk above and below. Exposures of chalk, containing clay layers several feet in thickness, occurring in stream cuts near the eastern border of the band of outcrop of the clay member in the vicinity of McKinney, Van Alstyne, and Whitewright, seem to indicate that the merging may occur by means of tongues and lenses of the chalk transgressing the upper and possibly also the lower limit of the clay.

C. I. ALEXANDER and J. P. SMITH

TEXAS CHRISTIAN UNIVERSITY
FORT WORTH, TEXAS
December 15, 1931

GIDEON OIL WELL NO. 3, LULING FIELD, CALDWELL COUNTY, TEXAS

The Gideon well No. 3, drilled in March, 1924, has been recognized as a freak phenomenon because the top of the producing horizon, the Edwards limestone, was encountered 373 feet deeper than in surrounding wells, and because the core samples from the formations below the top of the Austin formation showed a dip of approximately 45°.

The writer previously interpreted this condition as indicating that the well was drilled through the steeply dipping strata on the downthrown side of a buried fault.[1] However, no evidence of vertical displacement was revealed by surrounding wells. Therefore, the fault theory as accounting for this condition has to be abandoned.

During the last few years, the crooked-hole theory has been advanced as an explanation of the Gideon No. 3 phenomenon. A careful consideration of the available information connected with this well has led the writer to offer an explanation in the light of the crooked-hole theory. This phenomenon can be explained more logically and convincingly as a crooked hole than by the writer's previous explanation.

[1] E. W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 3 (May-June, 1925), pp. 632-54.

No data are available as to the verticality of the hole other than those revealed by the core samples and the log of the well. The drilling superintendent at the time the well was drilled reports no difficulty in "going in" or in "coming out" of the hole while drilling was in progress. No trouble was encountered while running the casing. The wear on the pump tubing and rods is not greater than in surrounding wells. These facts suggest that any crookedness in the hole is in the form of a gentle deviation from the vertical, the angle of deviation increasing progressively with depth.

The accompanying graph (Fig. 1) illustrates the course of the hole as fitted to the stratigraphic conditions revealed by the log. The deviation from the vertical was probably along the strike, because the thickness of the oil saturation was not more than 50 feet. If the deviation were northwestward, the top of the Edwards would have been encountered in the zone showing more than 50 feet of "pay"; but if the deviation were down the dip or southeastward, the bit would have encountered the top of the Edwards at the edge-water level. The calculated distance of the deviation measured on top of the Edwards is approximately 1,225 feet. That distance southeast of the well is in non-productive territory; that distance northwest is in territory having nearly 100 feet of saturation; and that distance along the strike is in the area where wells of 500-800 barrels of initial production were not uncommon.

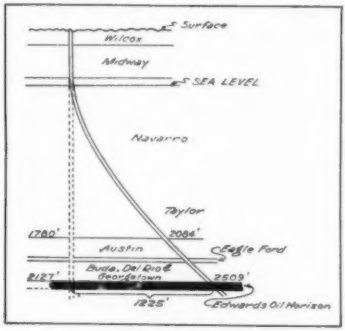

FIG. 1.—Suggested interpretation of Gideon No. 3, seen in cross section. Depths in feet.

The hole is probably vertical for the first 400 or 500 feet, as the drillers assert that the hole was started straight and vertical. However,

it is possible that the concretions in the Midway formation deflected the bit a trifle, initiating the deviation to such extent that in the Austin formation the angle of deviation amounted to 45°. Accordingly, the point where the bit encountered the oil horizon is probably 1,225 feet distant from that of the vertical course.

It is possible that other wells in the Luling field showed some deviation from the vertical, but none showed a difference in depth that indi-

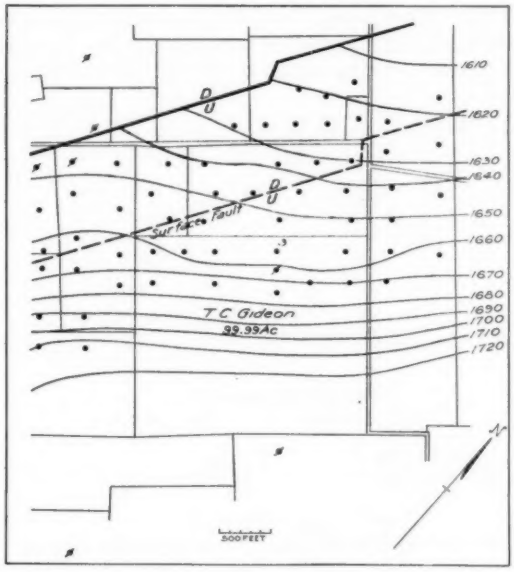

FIG. 2.—Structure map of Gideon No. 3 locality. Contours on top of Edwards oil horizon below sea-level. Contour interval, 10 feet.

cated beyond question that such difference was due to a crooked or non-vertical hole.

The cost of drilling and operation of the Gideon well No. 3 is of necessity greater than that of any normal well in the field, but because of the time elapsed since the drilling of this well it is impossible to determine the precise reasons for the evident deviation.

TABLE I

LOG OF THE UNITED NORTH AND SOUTH OIL COMPANY, INC., GIDEON NO. 3

Surface elevation, 471.8 feet above sea-level. Set 19 feet, 6 inches of 10-inch casing. Set 2,528 feet of 6⅝-inch casing. "Pay," 2,509-2,601 feet. Top of chalk, 2,084 feet. Initial production, 720 barrels, 4 per cent water. Completed, March 31, 1924.

Depth in Feet		*Depth in Feet*	
171	Clay, rock, and gravel	2,429	Del Rio clay
745	Shale and rock	2,462	Lime
1,745	Gumbo and shale; some boulders	2,465	Shale
		2,493	Lime
2,084	Chalk	2,499	Pack sand
2,216	Lime	2,509	Hard sand
2,219	Shale	2,511	Rock, oil sand
2,222	Lime, showing oil	2,513	Pack sand
2,229	Lime	2,523	Oil sand
2,232	Broken Del Rio clay	2,527	Pack sand
2,240	Sand and shale	2,535	Lime, rich oil core (2,533)
2,287	Lime and shale	2,536	Rock
2,309	Del Rio clay	2,548	Lime
2,364	Lime	2,550	Stained lime
2,368	Del Rio clay	2,552	Oil core
2,373	Shale	2,558	No formation given
2,374	Lime	2,564	White shale
2,393	Gumbo and gypsum	2,601	Lime
2,400	Gumbo		

E. W. BRUCKS

SAN ANTONIO, TEXAS
November 12, 1931

OVERTURNED PLUNGE ON OVERTURNED FOLDS IN SESPE-PIRU CREEK DISTRICT, CALIFORNIA

This is a description of a unique and interesting type of fold which has been found in a few places in the Sespe-Piru district. The type of fold is an overturned anticline in which the plunge increases from a comparatively low degree until it becomes vertical and finally overturns. "Overturned plunge" seems to be a self-explanatory and proper descriptive term for such a structure, and the writers have so used it.

The Sespe-Piru district includes the foothills north of Santa Clara River between Sespe Creek and Piru Creek, eastern Ventura County, California.

All of the Tertiary rocks from the upper Eocene to the lower Pliocene crop out in this district, although the Modelo formation, upper Miocene, forms the largest area. These rocks have been subjected to

intense pressure with a north-south component which has folded them into very tight structures, many of which are repeatedly overturned and faulted. Subsequent pressure with an east-west component has affected these folds and faults and has added greatly to their complexity. The compressive forces have created a very large and complicated eastward-plunging anticlinorium on which all of the Tertiary rocks from the upper Eocene in the western part of the area to the lower Pliocene in the eastern part of the area are exposed.

The following is a general outline of the manner in which this odd type of folding was formed. It has been definitely established that the rocks in the area were already sharply folded and in some places faulted by the north-south forces before the east-west pressures became prominent. These tight folds were parallel, although differing in lateral extent, and had a general east-west trend. At this time all of the folds plunged consistently eastward at a low angle. The subsequent pressures created a new set of folds and faults, whose general trend was normal to those first developed. This later folding and faulting altered the consistent eastward plunge of the structures so that in certain localities the plunge became westward, and in other localities it became very steep toward the east. In a few places this subsequent folding advanced until the eastward plunge became vertical and finally overturned toward the west before the intensity of the folding climaxed in faulting. The subsequent folding and faulting also had a marked effect on the faults which were already developed. The old fault planes were folded and in at least one place this folding became so acute that the fault plane itself was faulted and displaced. Figures 1 and 2 illustrate some of the interesting features caused by the subsequent folding of already well developed structures.

There are three overturned anticlines and one overturned syncline within the Sespe-Piru Creek district which have been greatly affected by these subsequent forces. Each of these structures formerly had a gentle and consistent plunge toward the east, but since the latter pressures were exerted, their plunge has increased in some localities until it has become vertical and actually overturned toward the west. In each structure a thrust fault is found a short distance from the point where the plunge became overturned.

The San Cayetano anticline in the vicinity of Sespe Creek is a well exposed example of an overturned anticline whose plunge has become overturned. The San Cayetano anticline is one of the most prominent structures of this region. It is a long overturned fold throughout its

FIG. 1.—Photograph of overturned plunge. *Tv* = Vaqueros. *Tsp* = Sespe.

entire length with the axial plane dipping north. In the vicinity of San Cayetano Peak the anticline plunges approximately 25° east and the degree of plunge increases steadily east of this point until it becomes vertical (the fold actually stands on end) at Sespe Creek. East of Sespe Creek the overturned anticline's plunge is overturned and finally becomes approximately 45° west. The folding climaxed in a thrust fault at this point. The generalized axial section AA' (Fig. 2) illustrates this feature.[1]

The photograph (Fig. 1) is a view northward across the axis of the San Cayetano anticline, east of Sespe Creek. At first glance the structure seems to be that of an overturned syncline with the axial plane dipping northward, but further inspection shows that the older rocks occur nearer the core. The Vaqueros (*Tv*) formation is lowest Miocene and the Sespe (*Tsp*) formation is Oligocene (?) in age. The rocks above the axis in the photograph are normal; those below are overturned. In reality the structure is that of an anticline whose plunge has become overturned until the anticline now lies upside down.

Judged from the small amount of fracturing and the great amount of squeezing, the sediments were evidently still quite plastic at the time the last compressive forces were applied. The squeezing, as shown by the axial section AA', is not limited to the shales, for there are many good

[1]The axial section AA' is simplified and diagrammatic but illustrates correctly the feature discussed.

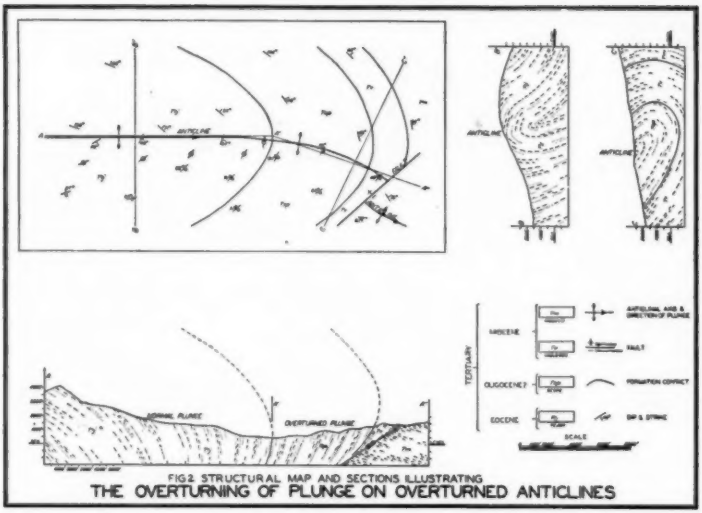

FIG. 2

examples of flowage in the sandstones themselves. Figure 1 illustrates the relatively small amount of fracturing at one of the most twisted parts of the fold.

C. E. LEACH[1] and F. A. MENKEN[1]

SAN FRANCISCO, CALIFORNIA
December, 1931

PECAN GAP CHALK: NEW LOCALITIES IN RED RIVER AND BOWIE COUNTIES, TEXAS

As a small addition to Miss Ellisor's[2] valuable paper, the following occurrences of Pecan Gap chalk are noted.

Red River County.—I. Dawson farm, ½ mile east and 1 mile north of English. Chalk crops out in field, and is 4 feet deep in cistern.

II. Squire Hunter farm, 1½ miles southeast of Dawson farm. Chalk is 16 feet deep in well near house.

III. Raleigh farm, on English-Henrietta road. Chalk west of lane, in lane, and east of lane.

IV. Creek bank and field, ¼ mile southeast of III.

[1]Geologists, Associated Oil Company, introduced by L. C. Decius.

[2]Alva Christine Ellisor, "The Age and Correlation of the Chalk at White Cliffs, Arkansas, with Notes on the Subsurface Correlations of Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8 (November, 1925), pp. 1152-64.

V. Henrietta School, 1 mile west of Henrietta Church. Chalk under culvert.

VI. Jackson farm, ¼ mile south of Henrietta Church. Chalk in two wells, 36 and 20 feet deep.

VII. Otto Knight farm, 1¾ miles south of English-Pine Springs road, and ¼ mile west of Pine Springs-Avery road. Chalk in small gully.

Bowie County.—VIII. Pine Springs-Avery road, 100 yards south of Mill Creek. Chalk in road ditch.

IX. Pine Springs-Spring Hill road, at Nine Bridges, 1¼ miles southeast of Pine Springs School.

X. Baker farm, ¾ mile from mouth of Mill Creek. Chalk in deep ravines, large exposure.

XI. Moore farm, 1½ miles from mouth of Mill Creek. Chalk in deep ravines.

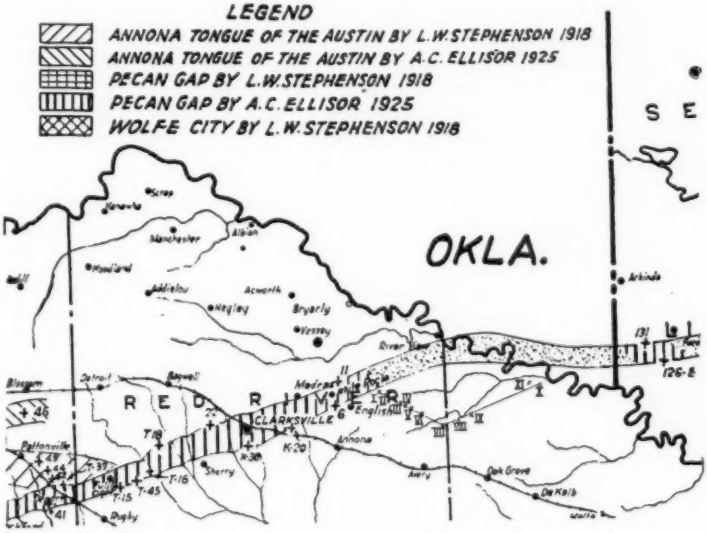

FIG. 1.—Newly found localities of Pecan Gap chalk (I-XI) in Red River and Bowie counties, Texas. Map modified from Plate 20 of article by Alva Christine Ellisor, "The Age and Correlation of the Chalk at White Cliffs, Arkansas, with Notes on the Subsurface Correlations of Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8 (November, 1925).

None of these outcrops is large, excepting those on the Baker and Moore farms, X and XI. All are in somewhat obscure places excepting VIII and IX, and in these the chalk has a soft character, which would not attract as much attention as a hard form.

An interesting feature in connection with these points is that, whereas the projection of the south edge of the outcrop in Red River County

comes within 2 miles of Red River at the Red River-Bowie County line, the point numbered VII is 7 miles from Red River.

H. N. SPOFFORD

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SHREVEPORT, LOUISIANA
August 13, 1931

EARTH CRACKS IN MISSISSIPPI[1]

Some exceptional cracks in the Yazoo clay member of the Jackson formation are found approximately a mile northwest of Pelahatchee, Rankin County, Mississippi, on the southeast slope of Ware Hill, ⅛ mile north of Pelahatchee Creek swamp, in the SE. ¼, Sec. 30, T. 6 N., R. 5 E.

Where well weathered, the Yazoo clay is a very plastic, calcareous, greenish yellow-to-black clay. In dry weather desiccation cracks form as large as 3 inches wide and several feet deep. Ware Hill, the top of which is 180 feet higher than Pelahatchee Creek swamp, is composed of Yazoo clay overlain unconformably by Pliocene red sand 60-120 feet thick.

The cracks at Ware Hill are peculiar because of a small ridge on the down-slope side of each crack, which really makes them small faults with the upthrown side forming the ridge. Many of the cracks are obscured by leaves and by slumping of the Yazoo clay which fills the crack, but those seen were more than 3 inches wide and more than 3 feet deep. The ridges are present on the downhill side of the cracks and range from 2 to 3 feet wide and from 1 to 1½ feet high with the steeper slope on the side next to the crack. In Figure 1 the cracks are shown by lines and

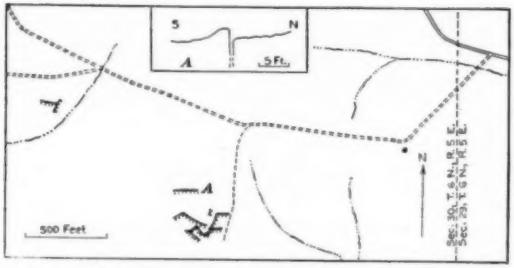

FIG. 1.—Map of part of SE. ¼, Sec. 30, T. 6 N., R. 5 E., Rankin County, 1 mile northeast of Pelahatchee, Mississippi. Cracks are shown by heavy lines; ridges by dots paralleling lines.

[1]Published by permission of the director, U. S. Geological Survey.

the ridges by dots. A diagram of the largest crack, *A*, is shown in the inset at the top of the figure. This crack is 6 inches wide, more than 3 feet deep, and 160 feet long. The accompanying ridge is 1½ feet high and 3 feet wide. On all the ridges large oak and pine trees have been lifted and tilted and some roots have been pulled out of the ground.

W. H. Baskerville, owner of the land, first saw the cracks nearly 5 years ago. Since that time he has looked for others and has found a few in the NE. ¼, NW. ¼, Sec. 36, T. 6 N., R. 4 E., 1½ miles west-southwest of those shown on the map. These cracks extend southeast and south with the ridge on the southwest and west sides respectively. The topography is flatter and there is no high hill immediately behind them. Trees have been lifted and tilted from the vertical to a noticeable extent on the ridges here also.

That the "faults" at Ware Hill are not ordinary dry-weather cracks is proved by the ridge and by the fact that the cracks have remained more or less open in rainy as well as in dry seasons. Baskerville has visited them at all seasons of the year and has always found them in nearly the same condition, although some of the cracks have been partly filled since he first saw them.

Many geologists familiar with the area have seen the cracks, but none has been able to explain the ridges satisfactorily. Some have suggested that the cracks may have been formed by an earthquake, but there is no record of any earthquake in the area. Moreover, one of the cracks, *A*, seems much fresher than the others. In this crack the Yazoo clay exposed on the north side of the ridge is less weathered than the surface clay, and has not slumped into the crack as has happened at most of the other cracks, which show the ridges but in which the crack is almost filled. Another possible explanation is that the ridges might be caused by subsoil creep. In wet weather the Yazoo clay becomes very plastic and landslides are characteristic. The slope at the foot of Ware Hill is not steep enough for a landslide, but a small amount of creep might be expected.

WATSON H. MONROE

WASHINGTON, D. C.
December 23, 1931

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 217-222

REVIEWS AND NEW PUBLICATIONS

Handbuch der Geophysik (Handbook of Geophysics). Edited by B. GUTENBERG. (Gebrüder Borntraeger, Berlin, 1931.) Band II, Lieferung 1, 564 pp., 183 figs. 7 × 10½ inches. Price: single, $24.50; if all the volumes of the Handbuch are ordered, $16.40 (special to Association members, $12.30). "Abkühlung und Temperatur der Erde" (Cooling and Temperature of the Earth), by B. Gutenberg; "Chemie der Erde" (Chemistry), by G. Berg; "Alter der Erde und geologische Zeitalter" (Age of the Earth and the Geologic Ages: Paleogeography and Historical Geology), by A. Born; "Der physikalische Aufbau der Erde" (Structure of the Earth: the Earth as a Whole, not the Structural Geology of the Earth's Crust), by B. Gutenberg.

Band VI, Lieferung 1, 312 pp., 134 figs. Price, single, $15.00; if all volumes ordered, $10.00 (special to Association members, $7.50). "Eigenschaften der Gesteine" (Properties of Rocks: Density, Elasticity, et cetera), by H. Reich; "Die elektrischen Aufschlussmethoden" (The Electric Methods of Prospecting), by H. Hunkel; "Theorie der gravimetrischen Aufschlussmethoden" (Theory of the Gravimetric Method of Prospecting), by E. A. Ansel; "Instrumente der gravimetrischen Aufschlussmethoden, 1. Teil" (Instruments of the Gravimetric Methods of Prospecting, Part I, The Pendulum), by O. Meisser.

Gutenberg's *Handbuch* is a much more pretentious and detailed work than its predecessor, the *Lehrbuch*. It is ultimately to consist of ten volumes, several parts of which have already appeared. The two sections which are before the reviewer are a characteristic German handbook and represent the compilation of an enormous quantity of data. Geological and geophysical research libraries should value the *Handbuch* for reference. Most individuals will find the cost rather high.

DONALD C. BARTON

HOUSTON, TEXAS
December, 1931

"Report of the Committee on Sedimentation, 1929-1930, Division of Geology and Geography." *National Research Council Reprint and Circular Ser. 98* (Washington, D. C., 1931). 97 pp. Price, $1.00.

This report is a summary of contributions to the study of sedimentation published during 1930. It does not pretend to be complete, but is very comprehensive. Sixteen members of the committee on sedimentation of the National Research Council contributed to this publication and eleven of these contributions are accompanied by bibliographies. Most of these bibliographies cover only the past year or two, but a contribution by Professor Kirk Bryan

of Harvard University, on "Wind-Worn Stones or Ventifacts," presents a complete bibliography comprising 258 titles.

Some of the papers and bibliographies cover the contributions in specific areas, as: "Sedimentary Research on the Pacific Coast, 1930," by R. D. Reed; "Research on Sediments by British Scientists during 1929-1930," by Henry B. Milner, and "Bibliography of Research on Sediments by Western Continental European Geologists in 1928 and 1929," by Édouard Paréjas. Other contributions cover specific fields of study, as: "Investigations of Marine Sediments at the Scripps Institution of Oceanography," by Thomas Wayland Vaughan; "Silt Studies in 1928 and 1929," by Kirk Bryan; "Varved Sediments," by Ernst Antevs; "Studies of Coarse Sediments, 1928-1929," by Chester K. Wentworth; "Recent Publications on Bentonite," by C. A. Bonine.

This report should be in the library of every serious student of sedimentation, if only to render available the bibliographies, comprising more than 600 titles. Few phases of sedimentation are left untouched by this report, although it does not deal specifically with certain important fields, for example, the origin and diagenesis of limestone, the origin of coal, and the changes that may occur in the characteristics of continuous shale formations.

More and more the oil geologist realizes the vital importance that sedimentation is destined to have in his future activities. In sedimentation, just as in micro-paleontology, the oil geologist must, if possible, attain great refinement and draw more critical and precise deductions than seem vital to the worker in pure science. For example, it is not enough for the oil geologist to recognize the probable source of coarse clastics. He must also be able to anticipate, with a fair degree of precision, the probable continuity and the probable characteristics of these coarse clastics between a point where he has recognized them in a well or on the surface and their source.

In his work with limestones he is handicapped by the many uncertainties that still exist, as those pertaining to the genetic relationships between limestone and dolomite and the origin and possible distribution, both horizontally and vertically, of porosity.

We are still unable to read the story of pre-depositional structure, topography, stream distribution, and possible petroleum source areas, from the characteristics and particularly from the changes, from point to point, in fine-grained sediments,—shales, marls, clays, and silts.

To the petroleum geologist this report is therefore not only a source of references, useful to him in his own studies, but also an encouragement and an inspiration through the evidence it presents of progress and of growing interest in a field of geology which to him is critically important.

K. C. HEALD

THE GULF COMPANIES
PITTSBURGH, PENNSYLVANIA
December 9, 1931

"Die Rolle der Humussubstanzen bei der Verwitterung" (The Rôle of Humus in Weathering). By FRITZ BEHREND. *Zeit. f. Prak. Geol.*, Vol. 39, No. 8. (Wilhelm Knapp, Halle, Saale, Germany, August, 1931), pp. 113-18.

The author of this paper points out that the humic acids themselves have a negligible effect in solution and weathering of rocks. In humus deposits there are formed a great series of organic acids grouped under the term humic acids. In addition, however, there is a considerable amount of carbonic acid and less amounts of sulphuric and phosphoric acids. The last is not a very effective rock solvent, because the phosphates are insoluble, but the other two inorganic acids are the real potent agents of rock weathering.

The humic acids do not form electrolyte solutions, but do go into solution as colloids. In this state they can not attack the rocks, and reaction can occur only after the rock material has been brought into an ionized condition by the inorganic acids. Then it is possible for the negative sol of the humic acid colloid to attach itself so firmly to the cation of the rock solution, such as iron or calcium, that the product has been falsely considered a humate. True humates may be prepared in the laboratory, because humic acids may be ionized very slightly in water solution, but they are not known as natural products of rock weathering. In bogs, where the conditions should be ideal for the formation of iron humate, the iron occurs only as the carbonate or as bog ore (limonite). In the latter situation, the humus material may be the precipitating or flocculating agent. The decomposition of rocks in contact with humus deposits is the same as could occur through the action of carbonic acid alone, and the humic acids are not potent factors in rock weathering.

R. W. CLARK

THE GULF COMPANIES
PITTSBURGH, PENNSYLVANIA
December 8, 1931

"Studies of Geophysical Methods, 1928 and 1929." By L. GILCHRIST, J. B. MAWDSLEY, and others. *Geol. Survey of Canada Mem. 165.* 227 pp., 66 text illus., 11 maps. (Ottawa, Canada, 1931.) Price, $0.45.

A. Investigations Made in Coöperation with the Radiore Company, Schlumberger Electrical Prospecting Methods, and Swedish American Prospecting Company, at the Abana Mine, on a Sphalerite-Chalcopyrite-Pyrite Sulphide Deposit. B. Research at the Mammoth Cave, Kentucky, on the Penetration of Strata by the Electro-Magnetic Field and on the Resistivity of Strata in Situ. C. Studies of Various Electric Methods at Various Mines. D. Torsion-Balance and Magnetic Surveys of the Hull-Gloucester and Hazeldean Faults.

The authors do not pretend to give a well-rounded finished survey of, and report on, the geophysical methods of prospecting. A little elementary statement of theory is given, but in general the volume consists of a series of succinct technical reports of studies in the application of the methods or in research in regard to special problems. It is a meaty volume for the advanced geo-

physicist and a notable contribution to the technical literature of geophysics. The engineer, mining engineer, or geologist who is not himself an advanced physicist in general will find it a little too advanced. The studies of Eve and Keys at the Mammoth Cave may prove important to the petroleum geophysicist in connection with improvement of electrical methods of prospecting in oil and to the miner in connection with signalling between the surface and the subsurface workings. Otherwise the volume is primarily of interest only in connection with mining geophysics.

DONALD C. BARTON

HOUSTON, TEXAS
December, 1931

"Zur Bildung der Europäischen Erdöllagerstätten" (Formation of European Oil Occurrences), by AUGUST MOOS. *Petrol. Zeits.*, Vol. 27, No. 40 (Berlin, October 1, 1931), pp. 711-24.[1]

The following is a summary of the author's conclusions.

1. The occurrences of oil in Roumania, Poland, and Russia are secondary in nature. The Hannover and Alsatian occurrences are also secondary, contrary to general opinion.

2. Oil migrates through porous horizons or through gaping fissures across the bedding. Migration within porous beds is important, especially in steep, vertical, and unconformable beds, and in a general way during the last phases of accumulation. Upward channels from the primary rocks are formed by gaping fissures most of which are perpendicular to the bedding, although near salt domes, oil migrates through radial fissures.

3. The time of migration was as follows: in Roumania and Caucasus, mostly during the Alluvial and Diluvial periods; in Galicia, after the Miocene overthrusts; in Hannover, a long time after deposition of the reservoir rocks, in some places during the Tertiary age or later.

4. Oil in the ground is not a positively stable element.

5. In the present lake and sea deposits, no oil is found.

6. The polybitumen of shales is transformed into ekgono-bitumen by the internal heat of the earth. A temperature of 150° is sufficient to make this process commence. In the European oil occurrences, the depth of the rocks in which the oil was originally formed is probably 3,000-5,000 meters and, at this depth, the temperature is sufficiently high for the mobilization of the bituminous content. Therefore, the formation of the oil is connected with epeirogenetic phenomena, and that of oil occurrences with orogenic processes.

7. In addition to polybituminous shales, limestones and dolomites also are rocks in which oil could have originated. This is probably true in the Lower Zechstein formations in which the Thuringian oil occurs. It is also possible that this Zechstein zone is the source of the Hannover oil.

It is necessary to study the bituminous rocks connected with salt deposits in order to decide whether they could be considered as source rocks for oil.

[1]Translated from German by A. Miller and W. P. Haynes.

RECENT PUBLICATIONS

CALIFORNIA

"The Cool-Water Timms Point Pleistocene Horizon at San Pedro, California," by Alex Clark. *Trans. San Diego Soc. Nat. Hist.*, Vol. 7, No. 4 (San Diego, December, 1931), pp. 25-42, map, chart.

COLORADO AND UTAH

"Origin and Microfossils of the Oil Shale of the Green River Formation of Colorado and Utah." *U. S. Geol. Survey Prof. Paper 168.* (Supt. of Documents, Washington, D. C., 1931.) Price, $0.60.

GENERAL

American Mining Law, with Forms and Precedents, by A. H. Ricketts. Third edition, enlarged and revised to date (1931). Published as *California Div. of Mines Bull. 98* (San Francisco, January, 1931). xxx + 811 pp. 5¼ × 8¼ inches. Limp leather. Price, postpaid, $2.00.

INDIA

"The Syntaxis of the North-West Himalaya: Its Rocks, Tectonics, and Orogeny," by D. N. Wadia. *Records Geol. Survey India*, Vol. 65, No. 2 (Calcutta, 1931), pp. 189-220, Pls. 3-8.

KENTUCKY

"Geology of the Deep Wells in Kentucky," by Willard Rouse Jillson. *Kentucky Geol. Survey*, Ser. 6, Vol. 42 (Frankfort, 1931). 647 pp., 4 illus. 6¼ × 9¼ inches. Cloth.

"The Paleontology of Kentucky—a Symposium Outlining Systematically and Briefly Describing with Stratigraphic References the Various Fossil Forms of Life Indigenous to the Rocks of the Commonwealth," arranged and edited by Willard Rouse Jillson. *Kentucky Geol. Survey*, Ser. 6, Vol. 36 (Frankfort, 1931). xiv + 469 pp., 33 text figs., 80 pls. 6¼ × 9¼ inches. Cloth.

NEBRASKA

"Correlation of the Big Blue Series in Nebraska," by G. E. Condra and J. E. Upp. *Nebraska Geol. Survey Bull. 6*, 2d Ser. (Lincoln, 1931). 76 pp., 62 illus.

PERU AND BOLIVIA

Boletin de la Sociedad Geológica del Perú (Lima), Vol. 4, No. 4 (December, 1927), pp. 1-95, published in 1931, contains among other articles the following.

"La génesis del petróleo su distribución geográfica en el mundo y el petróleo de nuestra montaña" (Genesis of Petroleum, Its World-Wide Geographic Distribution, and the Petroleum of Our Montanas), by Roberto L. Valverde. Pp. 42-71, illus.

"El petróleo de Caupolican, en Bolivia, y probable extension de sus yacimientos a la montaña de Madre de Dios" (Petroleum of Caupolican, Bolivia, and Probable Extension of Fields into the Montanas of Madre de Dios (Peru), by Otto A. Welter. Pp. 70-91, illus.

POLAND

"Structura karpat brzeżnych w rejonie Boryslawia" (Carpathian Structure Bordering the Region of Boryslaw), by K. Tolwinski. *Statystyka Naftowa Polski* (Polish Petroleum Statistics, Carpathian Geological Survey, Warsaw) No. 8 (August, 1931), p. 266, and a geological profile in colors.

"Pola naftowe Schodnicy i Urycza, na tle struktury geologicznej" (The Oil Fields of Schodnica and Urycz with a Map of the Geological Structure), by K. Tolwinski. *Statystyka Naftowa Polski*, No. 9, pp. 306-7, map.

ROUMANIA

"Der Bergbau auf Erdöl in Sarata-Monteoru, Rumänian" (Petroleum Mining in Sarata-Monteoru, Roumania), by J. Broz. *Inter. Zeit. f. Bohr., Erdölb. und Geol.*, Vol. 39, No. 19 (Vienna, October 1, 1931) pp. 145-48, 3 figs.

RUSSIA

"The Ekhahi Oil Field in North Sakhalin," by A. J. Kosygin. *Bull. Geol. and Prosp. Service U. S. S. R.*, Fas. 9 (Moscow, 1931), pp. 112-27, 1 fig., 1 map, 4 photos. Summary in English.

"The Okha Oil Region (North Sakhalin)," by A. Kosygin. *Trans. Geol. and Prosp. Service U. S. S. R.*, Fas. 53 (Moscow, 1931). 40 pp., 4 figs., 1 pl. Summary in English.

"Structure of the Eastern Coast of North Sakhalin Between the Troptu Gulf and Loevenstern Cape," by A. J. Kosygin. *Bull. Geol. and Prosp. Service U. S. S. R.*, Fas. 38 (Moscow, 1931), pp. 604-19, 1 fig., 1 map, 6 photos.

TENNESSEE

"A Preliminary Report on the Foraminifera of Tennessee," by Joseph A. Cushman. *Tennessee Geol. Survey Bull. 41* (Nashville, 1931). 116 pp., 13 pls.

"Notes on Sub-Surface Stratigraphy of Middle Tennessee," by Willard F. Bailey. *Jour. Tennessee Acad. Sci.*, Vol. 6, No. 2 (April, 1931), pp. 80-88.

TEXAS

The East Texas Oil Field. Mimeographed discussions presented at joint meeting of the East Texas Geological Society and the Dallas Petroleum Geologists at Tyler, Texas, December 17, 1931. 34 pp., 9 figs. (Sam Aronson, 306 Magnolia Building, Dallas, Texas.) Price, postpaid, $1.00.

"Osttexas, das jungste der grossen Ölfelder Amerikas" (East Texas, the Youngest of Large American Oil Fields), by A. Gugelmeir. *Petrol. Zeits.*, Vol. 28, No. 1 (Berlin, January 6, 1932), pp. 1-7, 3 figs., bibliog.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 223-226

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Frances Charlton, Maracaibo, Venezuela, S. A.
Chester A. Baird, Joe Netick, Leonard W. Henry

I. M. Goubkin, Moscow, U. S. S. R.
Stanley C. Herold, Eugene C. Templeton, Paul P. Goudkoff

Ralph Arnold Koenig, Carlsbad, N. M.
Alan Bruyere, Edgar Kraus, E. A. Obering

Warren Everett TenEyck, Long Beach, Calif.
H. A. Buehler, Dwight C. Roberts, D. B. Seymour

Harold Rollin Wanless, Urbana, Ill.
A. H. Bell, W. V. Howard, Frank W. DeWolf

FOR ASSOCIATE MEMBERSHIP

Calvin Harold Riggs, Muskegon, Mich.
R. B. Newcombe, K. H. Schilling, H. D. Crider

FOR TRANSFER TO ACTIVE MEMBERSHIP

Wallace Everett Richmond, Jr., Bradford, Pa.
J. B. Umpleby, Jerry B. Newby, Louis S. Panyity

GEOLOGICAL SOCIETY OF AMERICA ANNUAL MEETING

The forty-fourth annual meeting of The Geological Society of America was held at Tulsa, Oklahoma, December 29, 30, and 31, 1931, at the invitation of the Tulsa Geological Society. Societies participating in the program were the Paleontological Society of America in its twenty-third annual meeting, the Mineralogical Society of America in its twelfth annual meeting, the Society of Economic Geologists in its annual meeting, The American Association of Petroleum Geologists, and the Society of Economic Paleontologists and Mineralogists. Almost 200 papers were listed on the official program of all the meetings. The total registration was 721 persons.

The program of the joint session with The American Association of Petroleum Geologists included the following papers.

"Contribution of Petroleum Geologists to General Geology in California," by L. Courtney Decius
"Geology of the Northern Mid-Continent Oil District," by Sidney Powers
"Contributions of Petroleum Geology to Pure Geology in the Southern Mid-Continent Area," by F. H. Lahee
"Salt Domes of the United States," by Marcus A. Hanna
"Contributions of Seismology to Pure Geology," by J. C. Karcher
"Contributions of Geophysics to Geology," by C. A. Heiland
"Origin of Local Anticlines in the Mid-Continent," by Alex. W. McCoy

The general arrangements for the meeting and entertainment for the visiting geologists were in charge of Frank R. Clark, of Tulsa, assisted by several local committees. Special field trips were made to the west edge of the Ozark uplift; to the Oklahoma City oil field; to the Arbuckle Mountains; and to the Ouachita Mountains. The annual smoker, dinner, and dance were held at the Mayo, headquarters hotel.

The Tulsa meeting was unique in exceptionally large attendance and in distance from the northeastern part of the United States, where most of the meetings are held. The next annual meeting is to be held at Boston, the last week in December, 1932.

The new officers of The Geological Society of America are: president, R. A. Daly; vice-presidents, N. M. Fenneman, W. E. Wrather, A. N. Winchell, R. S. Bassler; secretary, Charles P. Berkey; treasurer, E. B. Mathews; editor, J. Stanley Brown.

New officers of the Paleontological Society of America are: president, R. S. Bassler; first vice-president, F. B. Plummer; second vice-president, E. H. Sellards; third vice-president, C. W. Gilmore; secretary, B. F. Howell; treasurer, C. O. Dunbar; editor, Walter Granger.

The officers of the Mineralogical Society of America are: president, A. N. Winchell; vice-president, Joseph L. Gillson; secretary, Frank R. Van Horn; treasurer, Waldemar T. Schaller; editor, Walter F. Hunt.

The officers of the Society of Economic Geologists are: president, B. S. Butler; vice-president, Ernest Howe; secretary, Edward Sampson; treasurer, W. M. Agar.

EXECUTIVE COMMITTEE MEETINGS, TULSA, DECEMBER 28 AND 29, 1931, AND JANUARY 1, 1932

The executive committee met at Tulsa, Oklahoma, December 28 and 29, 1931, and January 1, 1932, during the mid-year meeting of the Association. All members were present. The committee considered several matters of business to be presented at the annual meeting at Oklahoma City, March 24-26, 1932. A committee on the constitution and by-laws was appointed as follows: H. B. Fuqua, chairman, C. E. Dobbin, R. S. McFarland, F. A. Morgan, and W. C. Thompson.

OKLAHOMA CITY MEETING, MARCH 24-26, 1932

The seventeenth annual meeting of the Association will be held in Oklahoma City's newest hotel, the Oklahoma-Biltmore, which is now being com-

pleted. Registration, exhibits, and technical program are to be on the main (lobby) floor, so that all events of the meeting are easily accessible. General entertainment and arrangements are in charge of the Oklahoma City Geological Society committee, 2600 Ramsey Tower. F. H. Lahee, Box 2880, Dallas, Texas, has charge of the technical program. Exhibits are being arranged by Association headquarters, Box 1852, Tulsa, Oklahoma. Each member is being sent a convention announcement with reply cards for his hotel, field trip, and entertainment reservations.

Transportation.—Specially favorable railroad rates have been granted and identification certificates are being sent to each member, entitling him to purchase tickets on the basis of a fare and a half for the round trip. Diverse return route, stop-over, and 30-day return limit privileges will be granted. The identification certificate must be presented to ticket agent before ticket is purchased. The round-trip ticket must be purchased at beginning of trip; return parts of tickets must be validated at regular ticket office of return route at Oklahoma City.

For special air rates, apply to air-line offices.

Technical program.—In addition to papers previously announced, the following titles have been submitted.

"Progress of Drilling, and Oil and Gas Probabilities in Somerset and Fayette Counties, Pennsylvania," by Harley S. Gibbs

"Pre-Austin History of East Texas, North Louisiana, and South Arkansas, with Special Reference to Probable Areal Distribution of Eagle Ford and Woodbine Formations," by Sidney A. Packard and J. F. Magale

"East Texas Oil Field," by H. E. Minor and Marcus A. Hanna

"Buried and Resurrected Hills of Central Ozarks," by C. L. Dake and Josiah Bridge

"Geology and Gas-Oil Ratios in Oklahoma City Oil Field, Oklahoma," by C. L. Clifton

"Geology and Development of Oklahoma City Oil Field, Oklahoma," by William W. Clawson and D. A. McGee

"Contribution to Geology and Mining of Petroleum in Poland," by Karol Bohdanowicz

"Valuation of Natural Gas Properties,"[1] by E. A. Stephenson

"Coring in Oklahoma City Field," by R. W. Brauchli

"Tectonics of Oklahoma City Structure," by L. L. Foley

"Buried Igneous Rocks of Northern Louisiana, South Arkansas, and Western Mississippi," by C. L. Moody

"Pre-Permian Rocks in Big Lake Field, Reagan County, Texas," by E. H. Sellards

"Application of Reflection Seismograph," by Eugene McDermott

"Value of Bottom-Hole Pressures in Geological Interpretations," by C. V. Millikan

Abstracts of manuscripts should be sent to Association headquarters, Box 1852, Tulsa, Oklahoma, before March 1, for inclusion in the printed program. Authors should also send manuscripts in triplicate to F. H. Lahee, Box 2880, Dallas, Texas, by March 5, in order that the papers may be read and discussed.

[1]Contribution to a special publication of the Association, *Geology of Natural Gas*, to be issued the latter part of 1932.

ASSOCIATION COMMITTEES

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REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

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TRUSTEES OF RESEARCH FUND

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 16, NO. 2 (FEBRUARY, 1932), PP. 227-229

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

C. L. DAKE, professor of geology at the University of Missouri School of Mines and Metallurgy, Rolla, Missouri, is the author of "The Geology of the Potosi and Edgehill Quadrangles," a report of 233 pages and 26 plates, published by the Missouri Bureau of Geology and Mines, of which H. A. BUEHLER is director and state geologist.

T. C. HOKE, geologist with the Indian Territory Illuminating Oil Company, located at San Angelo, Texas, has been transferred to San Antonio, Texas.

JOHN A. MCCUTCHIN, affiliated with the Oklahoma Geological Survey, has been named by the American Gas Association Committee on Supply Men's Fund, of the Natural Gas Department, as recipient for the natural gas fellowship at the University of Oklahoma.

The Kansas Geological Society has elected the following officers for 1932: president, E. A. WYMAN, Amerada Petroleum Corporation; vice-president, W. A. VER WIEBE, professor of geology, University of Wichita; secretary-treasurer, EDWARD KOESTER, consulting geologist; director for two years, ANTHONY FOLGER, Gypsy Oil Company. The Society voted to sponsor the sixth of its annual field conferences, to be held in 1932. The area to be covered and the dates will be announced later.

H. DE CIZANCOURT, of Paris, is the author of two brief articles published in the Bulletin of the Geological Society of France in 1931: "A Microgranitic Massif in the Region of Andrafiavelo (East Coast of Madagascar) and Remarks on the Tectonics of the Region Between Ranobe and Manambolo (Eastern Madagascar)."

ROY H. HALL, district geologist for the Gypsy Oil Company at Wichita, Kansas, addressed the Tulsa Geological Society, December 21, 1931, on the subject, "General Review of Western Kansas."

G. W. PIRTLE, who has been in Michigan during the past two years, has returned to work in the East Texas area. The firm of Hudnall and Pirtle, geologists, is located at Tyler, Texas.

B. COLEMAN RENICK, recently with the Vacuum Oil Company, now has charge of the geological work for the Magnolia Petroleum Company in the San Antonio district, as a result of the merger of the two companies.

CARROLL H. WEGEMANN is spending the winter in Baltimore in work at the Johns Hopkins University, where he is also giving a series of lectures on petroleum geology. In October he lectured at Princeton University on the origin and accumulation of oil, and is expected to give another series of lec-

tures in March at the same university on certain structural problems. His address is 102 West 39th Street, Baltimore, Maryland.

CHARLES E. DECKER, professor of paleontology at the University of Oklahoma, has been appointed custodian of the files and records of the Oklahoma Geological Survey, discontinued the past year because of lack of legislative appropriation. Survey publications may be purchased from Professor Decker.

CHESTER W. WASHBURNE, consulting geologist, 149 Broadway, New York City, is the author of "Petroleum Geology of São Paulo," which is Bulletin 22 of the Commissao Geographica e Geologica do Estado de São Paulo, Rua Aurora, São Paulo, Brazil.

M. A. MELTON, of the geological faculty of the University of Oklahoma, presented a paper on "The Tectonic History of the Carboniferous" before the Shawnee Geological Society, Shawnee, Oklahoma, December 14, 1931.

HUGO BOCKH, director of the Royal Hungarian Geological Survey, died at Budapest, December 6, 1931.

LEON J. PEPPERBERG has resigned as consulting geologist for the Columbia Engineering and Management Corporation at Columbus, Ohio, and is returning to Dallas, Texas, to resume his consulting practice. His Dallas address is Box 574.

JOHAN AUGUST UDDEN, director of the University of Texas Bureau of Economic Geology and Technology, died at Austin, Texas, January 5, 1932, at the age of 73 years.

W. C. MENDENHALL is now director of the United States Geological Survey, GEORGE OTIS SMITH, former director, having been appointed chairman of the Federal Power Commission.

CLYDE M. BENNETT, formerly with the Vacuum Oil Company at Houston, Texas, has been elected vice-president of the Magnolia Petroleum Company. He assumed his new duties January 1, 1932, at Dallas, Texas.

LON D. CARTWRIGHT, JR., formerly of Beaumont, Texas, has opened an office for independent geological work in Terrell, Texas. His address is Room 10, Cartwright building.

IRA H. STEIN, geologist for the Continental Oil Company, has been transferred from Fort Worth to Amarillo, Texas.

STEPHEN H. ROOK, of the Gulf Refining Company, Shreveport, Louisiana, recently spoke before a joint meeting of the Fort Worth geological and paleontological societies, tracing the Cretaceous formations encountered in East Texas through Louisiana, Arkansas, and Mississippi.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT, who is residing at 1742 N Street NW., Washington, D. C., this winter, has accepted from the Dutch Government temporary appointment as director of The Netherlands Bureau of Mines, beginning May 1, for purposes of organization until the regular official is appointed. He will have an office at Maastricht, Holland, c/o Staats-

toezicht op de Mynen, and will direct government activities connected with the coal mines, labor and safety regulations, concessions, et cetera.

DR. VAN DER GRACHT has a paper entitled "The Pre-Carboniferous Exotic Boulders in the So-Called 'Caney Shale' in the Northwestern Front of the Ouachita Mountains of Oklahoma" in the November-December, 1931, issue of *The Journal of Geology*.

CHESTER M. GARDINER, formerly manager of the valuation engineering department and assistant chief geologist for the California Petroleum Corporation (now The Texas Company), has opened offices at 1121 Security Building, Long Beach, California, and will specialize in petroleum, geological, and valuation engineering work.

WALTER KAUENHOWEN, geologist, Berlin, Germany, is the author of an article, "Germany has New Oil Field with Unique Production Method," in the January 1, 1932, issue of *The Oil Weekly*.

At a recent meeting of the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, the following officers were elected: president, C. E. DOBBIN, U. S. Geological Survey; vice-president, A. E. BRAINERD, Continental Oil Company; vice-president, H. F. DAVIES, The California Company; and secretary-treasurer, G. G. LAW, U. S. Geological Survey.

The following officers of the West Texas Geological Society, San Angelo, Texas, have recently been elected: president, A. L. ACKERS, Stanolind Oil and Gas Company, San Angelo; vice-president, W. W. PATRICK, The Texas Company, Midland; secretary-treasurer, MINETTE RIES, Phillips Petroleum Company, San Angelo.

Members of the Fort Worth Geological Society have recently elected the following officers: president, PAUL L. APPLIN, 2200 Edwin Avenue; vice-president, WALTER R. BERGER, 1005 Fort Worth National Bank Building; secretary-treasurer, R. H. FASH, Fort Worth Laboratories.

Officers elected at a recent meeting of the Tulsa Geological Society are: president, ROBERT H. DOTT, 1521 South Yorktown; first vice-president, SHEPARD W. LOWMAN, Mid-Continent Petroleum Corporation; second vice-president, RALPH A. BRANT, Atlantic Oil Producing Company; and secretary-treasurer, THOMAS C. HIESTAND, W. C. McBride, Incorporated. R. S. KNAPPEN, outgoing president of the society, gave an illustrated lecture on "The Geology of Southwestern Alaska."

Members sponsoring applicants for membership should examine carefully the printed form before signing their names. Only the most recent form should be used. This is a 4-page, letter-size folder (each page, $8\frac{1}{2} \times 11$ inches) which shows on the upper right margin of the first page the space reserved for headquarters index reference. Older forms should be destroyed.

J. ELMER THOMAS, vice-president of the Bavarian Oil and Gas Corporation, recently organized by John Hays Hammond, Harris Hammond, and Mr. Thomas, has moved his office from Fort Worth, Texas, to 120 Broadway, New York City.